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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Elections

The following Members were elected at a meeting of Council held on January 11th, 1927:—

Fellows.—Mr. R. S. Capon and Mr. A. V. Roe.

Associate Fellows.—Mr. M. L. Bramson, A.C.G.I., Mr. H. Burroughes, Squadron Leader E. Harrison, Squadron Leader F. E. Hellyer, D.I.C., B.A., Lieut.-Colonel H. E. S. Holt, C.B.E., T.D., Mr. H. A. Hughes, Major R. E. Penny and Mr. W. E. Whedon, B.Sc.

Associates.—Mr. W. E. Barber, A.M.I.Mech.E., Mr. W. J. Blanch, Mr. H. J. Griggs, Mr. T. E. Johnson, Flight Lieut. W. G. Meggitt, M.C., Mr. G. W. Saynor, F/O. C. Sutton, F/O. J. H. C. Wake, B.Sc.

Student.—Mr. C. Chapleo.

Sir Samuel Hoare's Recent Flight to India

The following cable was sent to Sir Samuel Hoare on his arrival at Delhi:—"The Royal Aeronautical Society enthusiastically tenders to you, Sir, most sincere congratulations on the magnificent inauguration of the first link in the chain of Imperial Air Routes. The Society also wishes to record its admiration of the important part played by Lady Maud on this historic occasion."

Students' Section Secretaryship

It is greatly regretted that Mr. S. Scott Hall has had to resign the Honorary Secretaryship of the Students' Section in order to take up an appointment out of London. The Council wish to record their appreciation of the excellent work he has done in reviving this section of the Society's activities. Mr. C. G. L. Hutchinson has been appointed to take over the duties, and with the hearty co-operation of the Students' Section it is expected that he will continue and extend its present usefulness.

Subscriptions of Members

Members are reminded that all annual subscriptions became due on January 1st. The rates now in force are:—

Fellows	... ...	£5	5	0
Associate Fellows	... ...	£3	10	0
Associates	... ...	£2	2	0 (with Journal)
,,	... ...	£1	1	0 (without Journal)
Students	... ...	£1	1	0
Members	... ...	£2	2	0
Founder Members	... ...	£1	10	0

Library

The following books have been received and recently placed in the Library :— "Australia and Back," by Sir Alan Cobham; "Conquering the Air," by A. Williams; "Commercial Air Transport," by Lieut.-Colonel I. Edwards; "The Anodic Oxidation of Aluminium and its Alloys as a Protection against Corrosion," by the Department of Scientific and Industrial Research; Reports and Memoranda of the Aeronautical Research Committee, Nos. 1016, 1023, 1028, 1031, 1033, 1035, 1042, 1043; "Solar Activity and Long Period Weather Changes," by H. H. Clayton; Eleventh Annual Report of the N.A.C.A.; "Portable Steel Structures of Large Span," by H. N. Wylie; "The Royal Air Force as a Career," A.P. 1100; Transactions of the Institution of Engineers and Shipbuilders in Scotland; a set of catalogues of the Paris Aero Show, 1926; Berichte und Abhandlungen der W. G. L., Volumes II., III., IV., VII., VIII., IX. and X.; Reports of the Rijks-Studiedienst voor de Luchtvaart, Volumes I. and II.; Air Publication 1224, Camera, Air, Type F.8; Pamphlets relating to Aeronautics presented to the Association Technique Maritime et Aeronautique in June, 1926.

Members are reminded that they may borrow books from the Library either personally or by post, provided that they pay the cost of carriage both ways. No printed catalogue is as yet available; the books being kept on the card index system.

Silver Medal

The Silver Medal, awarded annually for the best paper published in the Journal, has been awarded to Professor B. Melvill Jones, A.F.C., F.R.Ae.S., for his paper on "The Control of Stalled Aeroplanes," published in the Journal for June, 1926.

The following awards have been made of recent years:—

1921. Mr. H. R. Ricardo—"Some Possible Lines of Development in Aircraft Engines."
1922. Colonel E. W. Stedman—"Some Technical Aspects of Aviation in Canada."
1923. Wing Commander R. M. Hill—"The Manœuvres of Inverted Flight."
1924. Major W. S. Tucker—"Sound Reception."
1925. Not awarded.

The medal will be presented to Professor Melvill Jones on the occasion of the Wilbur Wright Lecture in May.

Informal Discussions

An informal discussion has been arranged on "Comfort in Commercial Aircraft," to take place at 7.15 p.m., on Monday, February 7th. Air Commodore J. G. Weir, C.M.G., C.B.E., Fellow, who was Controller of the Technical Department during the War, and who has lately returned from Cairo, where he had flown in the first De Havilland "Hercules" to be sent East on the Cairo-Karachi service, will open the discussion. Through the courtesy of the Aero Club the discussion will take place at a dinner to be held at 3, Clifford Street, W.1, and members are advised to send in their applications for places at once to the Secretary of the Royal Aeronautical Society. The price of the dinner, not including drinks, will be six shillings. It is regretted that under the Aero Club rules, ladies cannot be invited on this occasion.

An informal discussion on "Materials with Special Reference to Corrosion," has been arranged to take place at the Society on Tuesday, February 15th, at 6.0 p.m., when Mr. W. H. Dyson, of the Department of Scientific Research, will open proceedings.

Annual General Meeting

The Annual General Meeting of the Society will be held on Tuesday, March 29th, at 5.0 p.m. It is hoped that as many members of the Society will attend as possible. The retiring members of the Council are:—Wing Commander T. R. Cave-Browne-Cave, C.B.E., Sir Mackenzie Chalmers, K.C.B., C.S.I., Mr. C. R. Fairey, C.B.E., F.R.Ae.S., Major R. H. Mayo, O.B.E., Lieut.-Col. M. O'Gorman, C.B., D.Sc., Colonel the Master of Sempill, A.F.C., Mr. T. O. M. Sopwith, C.B.E., Mr. C. W. Tinson, Mr. H. T. Vane and Sir Henry White-Smith, C.B.E. These are eligible for re-election if re-nominated.

Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the voters nominated that they are willing to serve.

Nominations of candidates shall be signed by the voters proposing them. Candidates must be nominated by two voters and no more.

Special Lecture

In addition to the programme arranged for the present Session, a Special Lecture will take place on Thursday, March 24th, at 6.30 p.m., at the Royal Society of Arts, when Major Wronsky, Director of the German Luft Hansa, will read a paper in English on the work of the Luft Hansa.

International Aeronautical Exhibition

The IVth International Aeronautical Exhibition will take place in Prague from June 4th to June 16th, under the auspices of the Czechoslovak Republic.

Data Sheets

The following Data Sheets will be published on February 15th and will be available for issue on and after that date:—

No. 1. Aerofoil Reductions, Aspect Ratio, Channel Effect.
No. 2. Hardness Tests.
No. 3. W, A, I and Z of Mild Steel Tubes.
No. 4. 18 oz. Flax Canvas. (Condensed from B.S. Specification, F.38.)
No. 5. Wrought Light Aluminium Alloy Tubes (Duralumin Tubes). (Condensed from B.S. Specification 2 T.4.)
No. 6. Wrought Light Aluminium Alloy Bar (Duralumin). (Condensed from B.S. Specification 2 L.1.)

Forthcoming Events

Tuesday, February 1st.—Joint Meeting with the Institution of Automobile Engineers, at the Royal Society of Arts, 7.0 p.m. Mr. A. H. R. Fedden, Fellow: "Supercharging for Aero Engines."

Monday, February 7th.—Informal Discussion. Air Commodore J. G. Weir, C.M.G., C.B.E., Fellow, will open a discussion on "Comfort in Aircraft."

Thursday, February 10th.—At 7.0 p.m., in the Library. Students' Section Lecture and Discussion on "The Articulated Connecting Rod," by Mr. E. Fearn.

Tuesday, February 15th.—At 6.0 p.m. Informal Discussion on "Materials with Special Reference to Corrosion," by Mr. W. H. Dyson.

Thursday, February 17th.—At 6.30 p.m., at the Royal Society of Arts. Major R. H. Mayo, O.B.E., Fellow: "The Design and Operation of Commercial Aircraft."

Saturday, February 26th.—Visit to the De Havilland Aircraft Works, Stag Lane Aerodrome.

J. Laurence Pritchard, *Secretary.*

PROCEEDINGS

FOURTH MEETING, FIRST HALF, 62ND SESSION

The Fourth Meeting of the Sixty-Second Session of the Royal Aeronautical Society was held in the Theatre of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, November 18th, 1926, when Mr. R. S. Capon read a paper on "Methods of Performance Testing and Analysis." Air Vice-Marshal Sir Sefton Brancker, K.C.B., Fellow, President of the Society, was in the Chair.

Sir SEFTON BRANCKER: I have to introduce to you to-night Mr. R. S. Capon, who has been an active pilot since May, 1916. In 1925 he was awarded the Groves Aeronautical Research Prize. He is now the chief technical officer at Martlesham and deals with the practical details of testing all experimental aircraft.

PERFORMANCE TESTING AND ANALYSIS

BY R. S. CAPON.

The first public account of the methods and principles of performance testing of aircraft is, it is believed, that presented to this Society in a paper read by Mr. H. T. Tizard in 1917. Since that paper appeared there have been few changes in testing methods—a fact which indicates how very well the requirements had been met by the proposals therein described. During the period of nearly ten years which has intervened, however, attention has been directed to the analysis of the data provided by the tests. At that early date, the designer was no doubt content to check his predicted performance by the information as to rates of climb and speeds made available by the work of the R.F.C. Testing Squadron; and if he found discrepancies, they were probably attributed to scale effect or to some other of those conveniently indefinite agencies which sometimes enable the theoretician who has been rash enough to predict a performance to evade the consequences.

In 1918 Professor Bairstow and Dr. Coales showed that, even with the rather limited data provided by the present standard tests, it may be possible for the designer to trace the causes of discrepancies. A scheme of analysis was proposed by which, with certain approximations and assumptions, the contributions to performance of aircraft and airscrew could be separated to some extent, and the designer could check up the various factors affecting performance one by one, and so had a better chance of determining the real causes of any disagreement between his predictions and test results. Hence, though it is no less true now than it was when Mr. Tizard's paper was read that—to quote the author's final statement—"it is only by accurate full-scale work . . . that we can hope to maintain a steady improvement in the efficiency of aeroplanes" it has now become more apparent that the scheme of tests must be made subservient to the subsequent analysis if full value is to be obtained from them.

It is proposed in the present paper to describe as briefly as possible some of the modifications which have been made in the methods of measurement and reduction to standard atmosphere at the Air Force testing station at Martlesham, and then to outline the form of analysis at present in use by the research section which came into being at that station about 18 months ago, and indicate the air tests, very different from the present standard system, which best meet the requirements of that analysis.

Turning to methods of measurement, the tests of maximum speed at various heights are carried out exactly as in the days of the R.F.C. Testing Squadron. The bubble statoscope is used to indicate level flight, and the reading of the air speed indicator is corrected for the instrument error and the "position" error, and finally converted to true speed by the well known formula. Two improvements have been effected. Firstly, the instruments are calibrated for temperature. In Fig. 1 are shown two typical calibration curves which explain

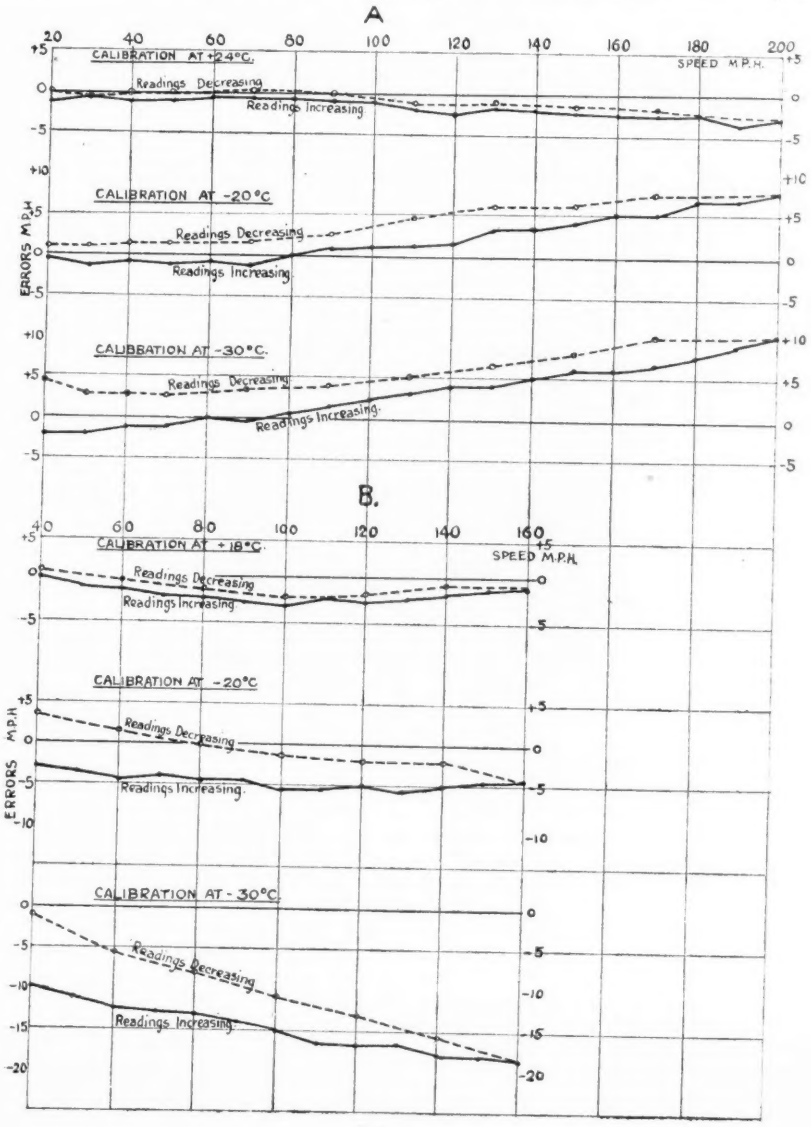


FIG. 1.

themselves. The instrument B is an obsolete pattern, fortunately, but errors in the instruments in use are still rather serious if not allowed for, as tempera- wires as low as −48°C. have sometimes been recorded during tests. Secondly, the measurement of the "position" error, *i.e.*, the error due to interference of the aircraft parts in the vicinity of the pitot head with the free flow of air past the head, is now more accurately obtained by the "suspended static head," a well known modification for test purposes of the pitot head due to the R.A.E. When, as sometimes happens, it is inconvenient to fit the suspended static head, the speed course is used, but errors of observation have now been practically eliminated by the use of a self-recording apparatus based on a principle in use at the Dutch testing station. It consists of two cameras, one at each observation post, which are free to turn about a vertical axis. Each camera is fitted with

FIG. 2.

an arrangement whereby the shutter is automatically tripped when the axis of the lens is directed to the starting (or finishing) point. Simultaneously with the tripping of the shutter, a recording pen marks a moving tape. Seconds are also recorded on the tape by another pen. Observers at each observation post turn the camera to follow the aircraft as it passes and photographs are auto- matically secured which show how far the aircraft was over or short of the starting and finishing points at the moment when the time records are taken. In Fig. 2 is shown such a record. The line ruled on the photograph shows the terminal point of the speed course, and on this occasion the observer has followed the aircraft so accurately that no correction would be required for "over" or "short." By this means the speed course errors are reduced to quite negligible quantities even on a course of only a mile length. The speed course measure- ments are only used to determine the "position" error from the difference between the recorded speed and the speed indicated in the aircraft, however. Runs of at least three minutes' duration are considered to be required for attaining a steady maximum speed, and such runs are not possible on the speed course at Martlesham.

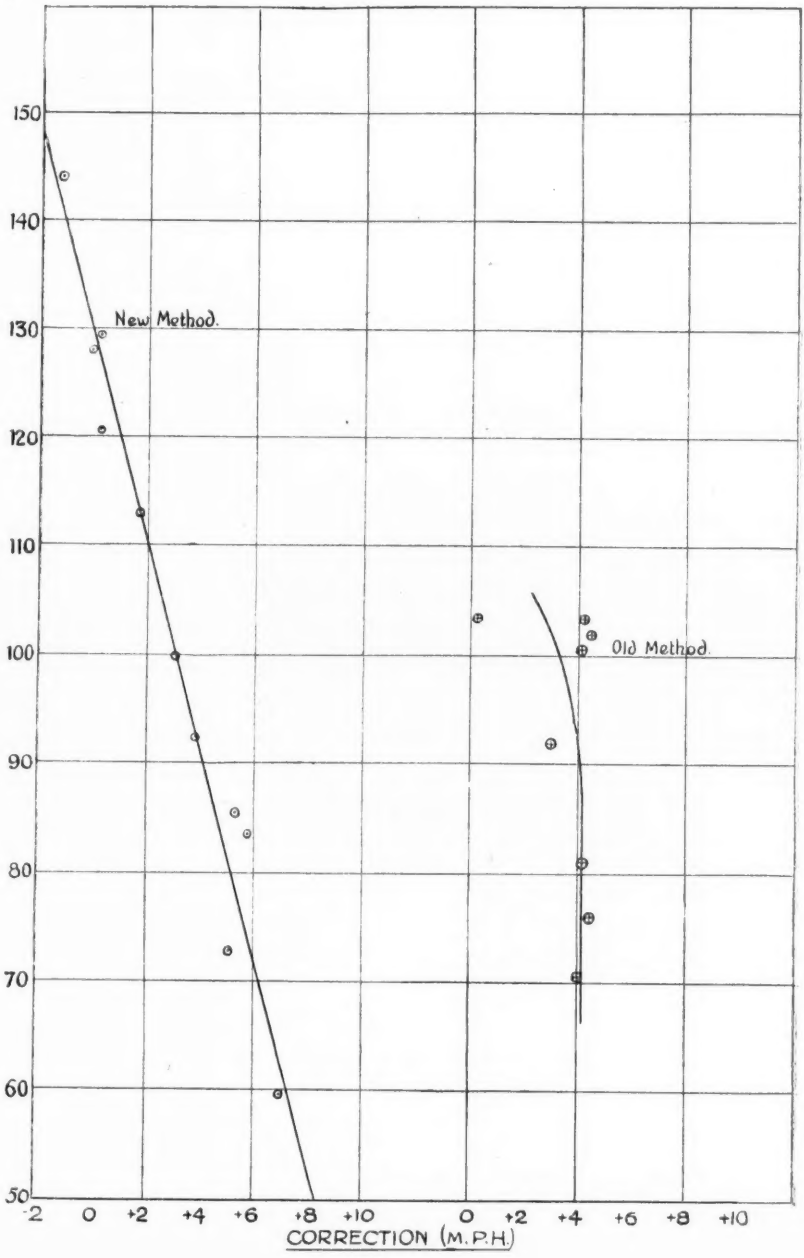


FIG. 3.

Speed Course Results.

◉ Observed position errors.

——— Mean curves.

The intrinsic agreement of results obtained by the original method, which was subject to personal errors on the part of the speed course observers, and those now obtained, are shown in the two plots of position errors by speed course observations in Fig. 3, picked out of the Martlesham records as showing about the average errors by the two methods. The errors from the automatic records are probably almost entirely due to the observation of air speed in the aircraft, and are satisfactorily small. It is clear that the original method was liable to occasional rather large errors probably due to a temporary lapse on the part of the observers. The errors when the suspended static head is used are of about the same magnitude as those resulting from the use of the automatic speed course apparatus.

Turning now to the measurement of rates of climb, the rate of climb meter for determining the air speeds which give maximum rate of climb, described in Mr. Tizard's paper, was replaced apparently at an early date by the well known method of partial climbs, in which the climbs through a small height interval are carried out at various air speeds, and the indicated air speed for maximum rate of climb determined by plotting the time required against indicated speed. Now in order that the tests may not require too much flying time it is necessary

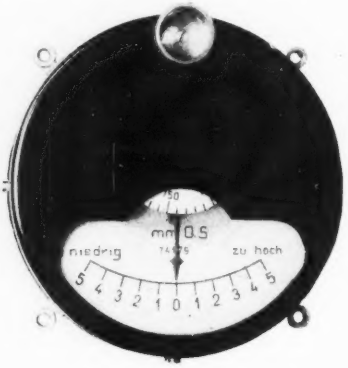
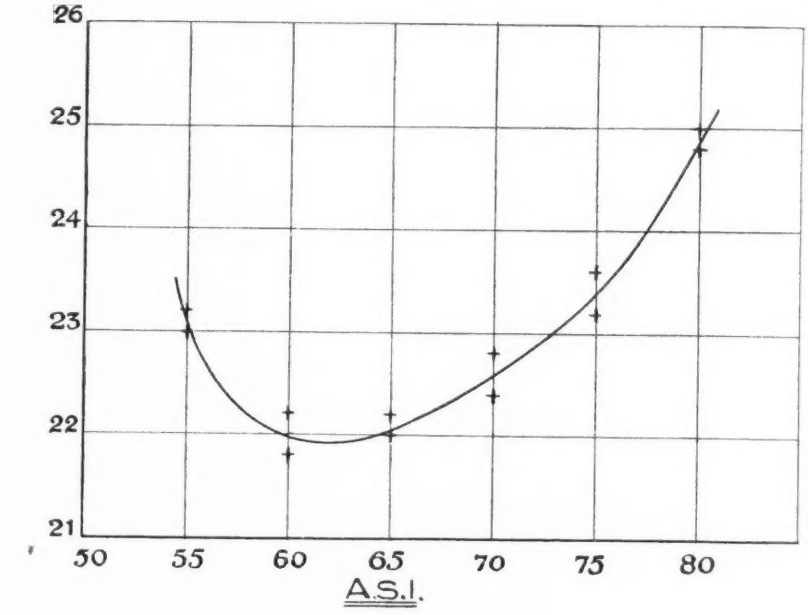


FIG. 4.

to use small height intervals, and in consequence, to obtain accuracy, the height must be read with very little error. For example, if the height interval is 1,000 ft., an error of 50 ft. in reading at each end of the interval may, if the errors happen to have opposite signs, give an error of 10 per cent. in the resulting rate of climb, and the final climb data will in consequence have errors of the order of 10 per cent. To overcome this difficulty the "Askania" statoscope (so called) shown in Fig. 4 is used. A full description would be too lengthy for inclusion, but the method of operation is as follows. The mean height for the group of partial climbs is set on the upper dial (in mm. of mercury) and the instrument then indicates very accurately, by means of the lower scale, heights over a range in mm. of mercury of from 5 mm. below to 5 mm. above the height set. The scale of the indicator permits of a reading of height to about 10 ft. Vertical atmospheric currents are still liable to give rather a large scattering of the points in the final plots to find best rate of climb, but a very definite improvement results from the use of the instrument, as is shown by the typical results exhibited in Fig. 5.

The points + show the individual observations, duplicated in the tests with the "Askania" statoscope, and the curves are smooth curves to represent them.


26
25
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55
60
65
70
75
80
A.S.I.

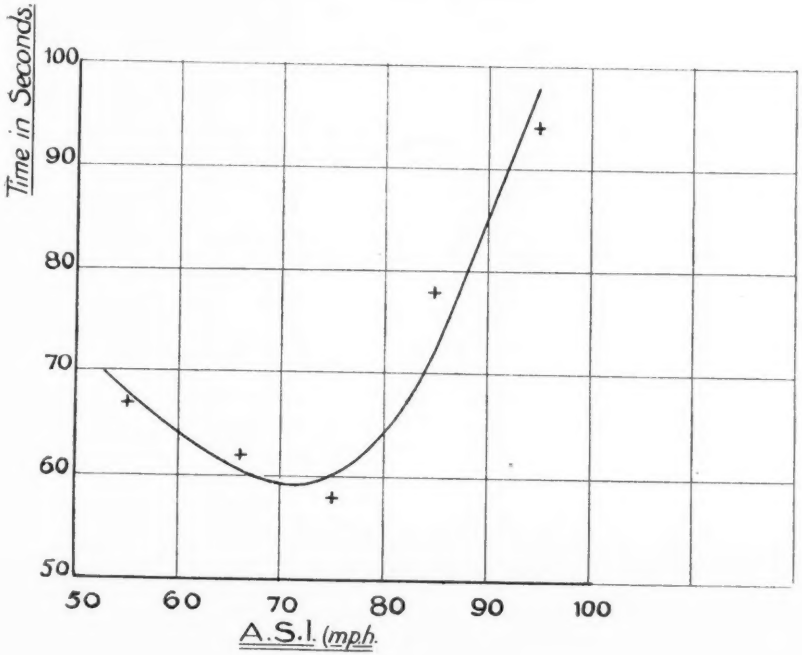
Time in Seconds.
100
90
80
70
60
50
50
60
70
80
90
100
A.S.I. (mph.

FIG. 5

Assuming the mean curves to be correct the percentage error in the time to climb through the height interval is

For the "Askania statoscope ... ... 0.7 per cent.
,, standard altimeter ... ... 4.2 ,,

and these figures therefore give a rough measure of the relative accuracy with which the climbs at the air speeds indicated by the partial climbs would agree with the maximum climb. If the speeds obtained by the use of the altimeter were used, there would be a considerable risk that the climbs resulting would not be quite the best of which the aircraft would be capable.

It would be incorrect to suppose from the good accuracy of the record shown in (*a*) Fig. 5 that the difficulties of obtaining satisfactory partial climbs have been overcome. Even the increased accuracy made possible by the "Askania" statoscope does not obviate the all too frequent occurrence of very irregular records, probably due to variable up and down atmospheric currents, and much time is lost in this test.

The method of recording rates of climb in the climbs at the air speeds indicated by the partial climbs has not been much altered. Watch times are taken every thousand feet, and recording barographs are also carried. The means of the one or more barograph rates of climb and the rates resulting from the watch times are taken. Recently, a low temperature and low pressure chamber constructed at R.A.E. has been provided, and it has become possible to calibrate the barographs and altimeters at low temperatures combined with low pressures, so that the actual physical conditions during the tests can be closely simulated. Rather large errors have been found in the altimeters at low temperatures, amounting to $-1{,}200$ ft. at 20,000 ft. and $-40°$C. in the worst case, but such errors can now be allowed for. The temperature errors in the barographs are much smaller, amounting to 200 ft. at $-30°$C. at maximum. The effects of cold on the watches and the barograph clocks are negligible.

The method of reduction of the results to standard atmosphere has been revised. As long ago as March, 1918, it was shown by tests at R.A.E. that the assumption that the variation of engine power with height was a function of the density of the surrounding air gave poor agreement of rates of climb on days when the air temperatures at the same density were different, but that good agreement was obtained if it was assumed that the power depended upon the pressure. In aircraft tested recently at Martlesham, considerable temperature variations at the same height occurred in the course of the tests. Pairs of climbs with large differences of temperature were reduced on the density and pressure bases, and the average difference (rate of climb at higher temperature)—(rate of climb at lower temperature) was taken for each pair and for each basis of reduction. The mean temperature differences were also determined. The final results for each aircraft were then meaned and the following figures were obtained:—

Density basis. Mean difference of rates of climb + 66 ft./min.
Mean temperature difference + 10°C.

Pressure basis. Mean difference of rates of climb − 4 ft./min.
Mean temperature difference + 10°C.

It will be seen that the density basis gives a considerably higher rate of climb on a warmer day, while the effect of the atmospheric temperature variations on the results of the pressure reduction are inappreciable. Temperature effects on instruments are however included in the above results, as no facilities existed at Martlesham at the time when the tests were carried out to calibrate instruments for temperature. It is difficult to assess the extent to which the evidence for the dependence of engine power on pressure rather than density, exhibited by the above figures, would be affected by the temperature errors of

the instrument. It seems probable, however, that the conclusions would be but little affected, but that if any such effect were appreciable it would tend to show that the law of dependence would be between density and pressure, but very much nearer the latter. All aircraft instruments are now calibrated for temperature, and it is hoped in a short time to have further and more reliable statistical evidence as to the dependence of engine power on pressure or density.

In view of the above evidence, in agreement with previous tests at R.A.E., and to eliminate the very serious non-standardisation resulting from the use of the assumption that engine power varies as the density, the pressure basis has now been authorised for reduction of performance to the standard atmosphere. The question is frequently asked whether reduced performances will be increased

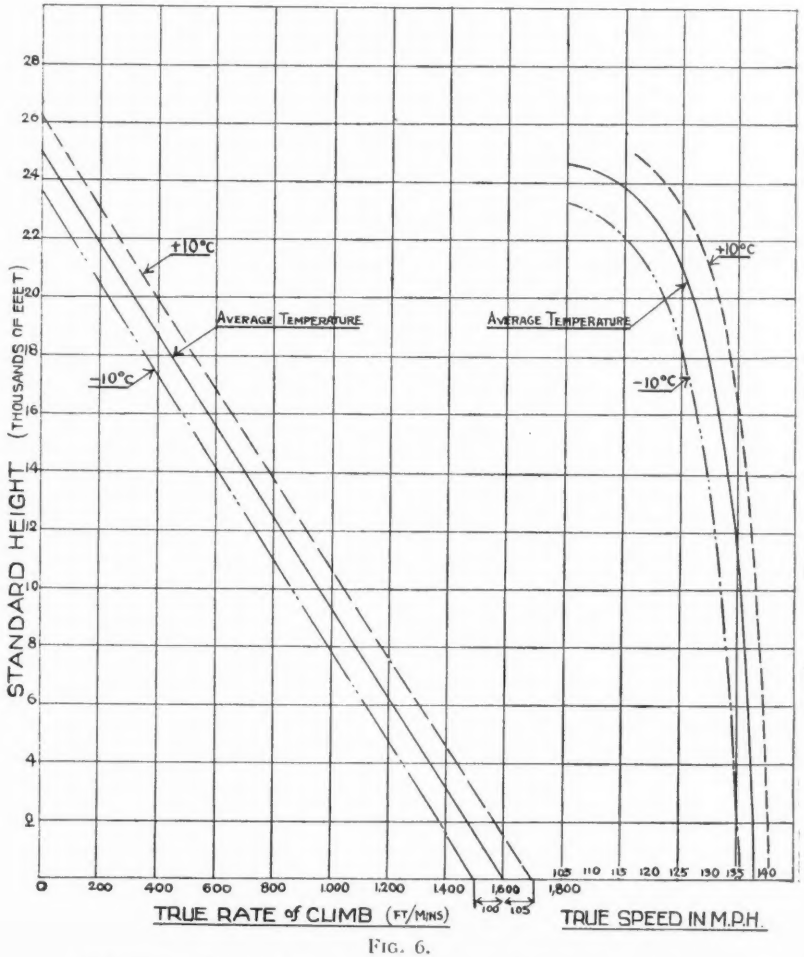

FIG. 6.

Variations of Rates of Climb and Maximum Level Speed, by Density Reduction for Maximum Summer and Minimum Winter Temperature.

or decreased by the adoption of the pressure law. If the actual atmosphere happens to be the standard atmosphere on a particular day, then the pressure and density reductions give the same results, and as the standard atmosphere was selected as representing average conditions in these latitudes, it follows that performance on the average will be the same whichever basis is used. Summer tests results will be slightly poorer, but winter tests will be correspondingly improved. In Fig. 6 is shown the difference which results in the rate of climb and level speed curves on a typical hot day in summer and cold day in winter, with the density reduction, supposing the pressure basis to be correct. The rate of climb and speeds reduced on the pressure basis would be represented by the curves marked " average temperature " whatever the prevailing atmospheric temperatures.

The way in which some of the errors of the standard system of tests have been reduced by more thorough calibration and by revision of the basis of reduction has now been indicated. The improvements in accuracy due to the calibration of instruments at low temperatures and in other ways have been described in their bearing on the well known standard system of tests to simplify the explanation. The application to the new tests, which will shortly be described, is very similar and does not require a separate description.

The very important question of the probable error of the pilot's observations arises. There is little doubt that such errors after a little practice are within 1 per cent. at Martlesham. For example, the errors in the speed course results of Fig. 3 (new method) are compounded of an inappreciable error in the ground observations, an error due to fluctuations in the strength of the wind and the pilot's error in reading his speed. The mean error of the observations is 0.3 per cent. of the speed, and it follows that the pilot's error cannot in this instance have been much greater than this. Other considerations point to the same high value of accuracy in other test data, in so far as the pilot's observations are concerned. There appears to be an impression in some quarters that the errors of observation in air tests are so large that a high order of accuracy in the reduction of such tests is not worth while. It is an unfortunate confession to come from the technical side, but there is little doubt that for some time the pilot's errors have been considerably less than the errors which may be described as " technical," *i.e.*, errors due to the air conditions being insufficiently simulated in the calibration of instruments, to the use of the " density " basis of reduction and to similar causes. There is little doubt that the errors of air tests, when instruments are properly calibrated and a correct basis of reduction to standard atmosphere is used, will be such that any approximation involving an error of more than 1 per cent. in the analysis will be liable to do injustice to the accuracy of the test data.

It seems probable that the chief sources of error remaining will be vertical atmospheric currents. Such currents affect not only rates of climb, but level speeds also, because an aircraft, to maintain its height, must be ascending or descending relative to the air in which it is flying. For example, a vertical current of 1 m.p.h. will cause an error of the order of 2 m.p.h. in the estimate of level speed of a normal aircraft. Apparatus has been constructed by which it is hoped to measure such currents, at least in the lower layers of the atmosphere, by forming an artificial cloud by release of stannic chloride, and photographing it simultaneously at regular intervals from the two camera obscuras at Martlesham; but whether the air currents will be sufficiently constant to enable tests to be corrected for their effects is not yet known.

Two methods of compensating for the effects of vertical atmospheric currents have been considered. In the first, the flight path recorder developed at R.A.E. is used. In the second, a " calibrated aircraft," *i.e.*, an aircraft for which a diagram similar to Fig. 9 has been prepared is flown " in formation " with the

aircraft for test. It is believed that the former has already proved successful, but it is doubtful if the latter will be practicable.

We now come to the problem of performance analysis and the system of tests best suited to provide the data for the purpose. The importance for the progress of aircraft development of supplying the designer with information by which he can not only check his predicted maximum level speeds and rates of climb by accurate full-scale tests, but also compare separately the aircraft and airscrew coefficients with his design values, need not be stressed. If, however, such comparisons are to be of real value to him, it is essential that a certain degree of accuracy should be definitely attributable to the test data and analysis. A rough analysis will tell him only what he already knows, viz., that his design aircraft and airscrew coefficients are roughly in agreement with the full-scale values. The designer is really only interested in the last two or three per cent. of accuracy which may enable him to check any allowance he may have made for scale effect, or the effect of slipstream on lift, or other small corrections. An analysis and the appropriate system of tests must therefore fulfil certain conditions if it is to meet his requirements.

The first consideration which presents itself is that the accuracy of the test data, as has been indicated, precludes any of the approximations which are frequently made in discussing aircraft performance, if justice is to be done to the pilot's observations. For example, the cosine of the angle of climb is frequently replaced by unity, the angle of incidence where it occurs explicitly in the aerodynamic equations is replaced by zero, and slipstream effect on lift is neglected. In an aircraft of high performance, the first of these may be equivalent to neglecting 6 per cent. of certain coefficients, the second to an error of the order of 20 per cent. in other coefficients, and the last may, as will be seen later, amount to 12 per cent. in the lift coefficient. It is clear, therefore, that the accuracy of the air tests is liable to be lost unless the analysis is quite rigorous.

A second principle which it is considered should underlie the analysis of performance is that the introduction of any assumptions required to complete the analysis should be postponed to the latest possible stage in order that the maximum amount of information may be obtained without their use. It will be seen later that certain important information is unobtainable from full-scale tests, and the difficulty has been overcome in some proposed analyses by introducing generalised airscrew curves, *i.e.*, curves which are supposed to be applicable to all airscrews. By postponing the introduction of the curves or other assumptions to a late stage in the analysis all the information with the exception of an unknown constant can be obtained without their use and is therefore free of any errors the use of such assumptions may entail.

A third and less important consideration is that the tests should cover the greatest possible range of flight conditions, in order that the designer may check his original data to the fullest possible extent. Throttled, as well as full throttle tests are therefore required. Lastly, it seems desirable that as little use as possible should be made of bench test engine power data, as no direct check of the power is easily obtained during the tests, and errors may therefore be introduced.

By observing these guiding principles as far as possible the best use can be made of the very considerable accuracy of the air tests, certain information can be provided as obtained by direct and rigorous analysis from the tests, and as having in consequence definite probable errors deducible from the probable errors of the original observations, and the effects of different assumptions made to extract the remainder of the information required on the final results can be more readily seen.

It is convenient to use non-dimensional quantities in discussing the analysis of performance, because by doing so the number of separate variables which

must be taken into account is reduced and the discussion is simplified. For example, speed V always occurs in the aerodynamic equations with density ρ and wing loading w, in the form $V\sqrt{(\rho/w)}$, and much greater clarity results if we take this as a new variable. The variable $V\sqrt{(\rho/w)}$ is of a similar type to the lift and drag coefficients; its dimensions are zero. Such variables are conveniently divided into two classes. The classes have not yet been distinguished in aeronautical literature by specific names. To avoid circumlocution, the quantities falling in them will be referred to as "primary variables" and "secondary variables." A list of such variables is contained in the following table. The nomenclature is sufficiently standardised to require no definition except that V_c represents rate of climb, f the engine power factor, and fP is the power, conveniently written in this form because P is then the power at the ground at the same airscrew rotation rate. Both the primary and secondary variables are taken from Bairstow's *Applied Aerodynamics*.

NON-DIMENSIONAL VARIABLES.

PRIMARY VARIABLES.

Name.	Constitution.
Speed variable ...	$V\sqrt{(\rho/w)}$
Rate of climb variable	$V_c\sqrt{(\rho/w)}$
Power variable ...	$(fP/W)\sqrt{(\rho/w)}$
Airscrew variable ...	V/nD

SECONDARY VARIABLES.

Name.	Constitution.
Scale variable ...	VD/ν
Air compressibility variable	V/a
Airscrew distortion variables	$\left\{\begin{matrix}(1/\rho)(w/g) \\ E/\rho V^2\end{matrix}\right.$

All coefficients, *e.g.*, k_L, k_D, k_T, etc., however constituted, and all angles, *i.e.*, angles of climb, incidence and attitude of the airscrew axis to the horizontal.

In the above
ν = kinematic viscosity.
a = velocity of sound in air.
E = Young's modulus for the material of the airscrew.

It will be noted that the primary variables are those normally used in performance calculations, and the effects of the secondary variables are usually allowed for, when taken into account at all, by small empirical corrections to the final results.

Supposing the effects of the secondary variables are negligible over the range of speeds, air densities, etc., of the tests, then it has been pointed out by Prof. Bairstow that only two of the primary variables are independent. Otherwise expressed, if we give values to any two of them, the values of all the others are immediately fixed.

A full discussion of the consequences of this important circumstance would be too lengthy for inclusion in the present paper, but some very valuable formulæ and conclusions will be recapitulated as having an important bearing on the analysis of performance. The proofs of the statements are in some cases obvious and in others will be found in published work.*

(1) The primary variables may be plotted as families of curves in a two-dimensional diagram with any two of them, or functions of two or more of them as co-ordinates. Such families of curves are unaffected by any change of scale or total weight of the aircraft. They include effects of slipstream, and all effects except those due to secondary variables. It should be noted that full throttle curves can be plotted on the diagram, but they are in general affected by change of total weight, etc., because they are not strictly aerodynamic curves, but include engine characteristics.

(2) The condition that the full throttle curves in such a diagram should be

* Bairstow's "Applied Aerodynamics." R. & M. No. 608. R. & M. No. 984.

the same for a change of total weight and/or scale is that it should be possible to represent the engine power at the ground in terms of the airscrew rotation rate (n) by a function of the form n^r, where r is a constant applicable to the particular engine. For present standard service engines, r varies from 0.7 to 1.2, and the power can be so represented with an error of not more than 1.5 per cent. over the working range. It follows that to a close approximation the full throttle curves are unaltered. After a change of total weight from W to W', wing loading from w to w' and linear dimensions from D to D', a full throttle curve for a height at which the air density is ρ should be re-labelled with a density ρ' given by the equation :—

$$fW'/f'W = (D/D')^r \, (\rho' w/\rho w')^{(r-1)/2}$$

where f and f' are the power factors, expressible (after reduction to a standard atmosphere) in terms of ρ and ρ'.

(3) If marked letters refer to one set of conditions of flight, *i.e.*, at given weight W', wing loading w', air density ρ' and linear dimensions D', then flight is possible at another set of conditions denoted by unmarked letters, if the speeds V, rates of climb V_c, etc., under the second conditions are obtained from the speeds V', rates of climb V'_c, etc., under the first set, by the equations :—

$$(V/V') = (V_c/V'_c) = (nD/n'D') = (fP/f'P') \, (W'/W) = \sqrt{(\rho' w/\rho w')}$$

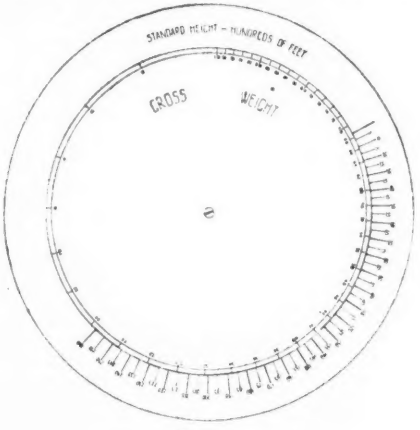

FIG. 7.

In these equations, fP and $f'P'$ are the powers required at the airscrew shaft under the two sets of conditions. If one set of speeds, etc., was obtained at full throttle, then the power required for the second set will be the power available at full throttle at the new air density and airscrew rate of rotation if the conditions in (2) are applicable, *i.e.*, if the ground engine power P is proportional to n^r, and if the air densities ρ and ρ' are connected by the equation there given. The above equations were given by Dr. Coales, and the sets of conditions were called by him "equivalent conditions." It is convenient to refer to the set as the "principle of equivalence."

(4) The equations of the principle of equivalence may be used for the reduction of performance to the standard atmosphere, either on a density or pressure basis, or on any law of dependence of the power factor on both pressure and density. They may also be used for the prediction of change of performance at full throttle with change of total weight. In this problem $D = D'$, and it may be shown that with an error of not more than 2 per cent. in the required speeds,

rates of climb and airscrew rates of rotation, the equations may be replaced by

$$V = V', \quad V_e = V'_e, \quad n = n',$$

at densities ρ and ρ' connected by the equation $Wf' = W'f$ provided the change of total weight is not more than 20 per cent. of the total weight. A slide rule (see Fig. 7) to solve the last of the above equations can readily be constructed if the relation between the power law and the standard height is known. To use it, W on the inner scale is set to register successively with a number of arbitrarily chosen heights H_1, H_2, etc., and the corresponding heights, H'_1, H'_2, etc., are read off opposite W'. The values of V, V_e and n at the heights H_1, H_2, etc., are replotted at the heights H'_1, H'_2, etc., and a curve through the points gives the required performance at the new total weight. The type of agreement obtained is shown by Fig. 8. Rates of climb and level speeds are represented for two aircraft tested at two weights. The points show predictions from the tests at the lighter weight of performance at the heavier weight and are seen

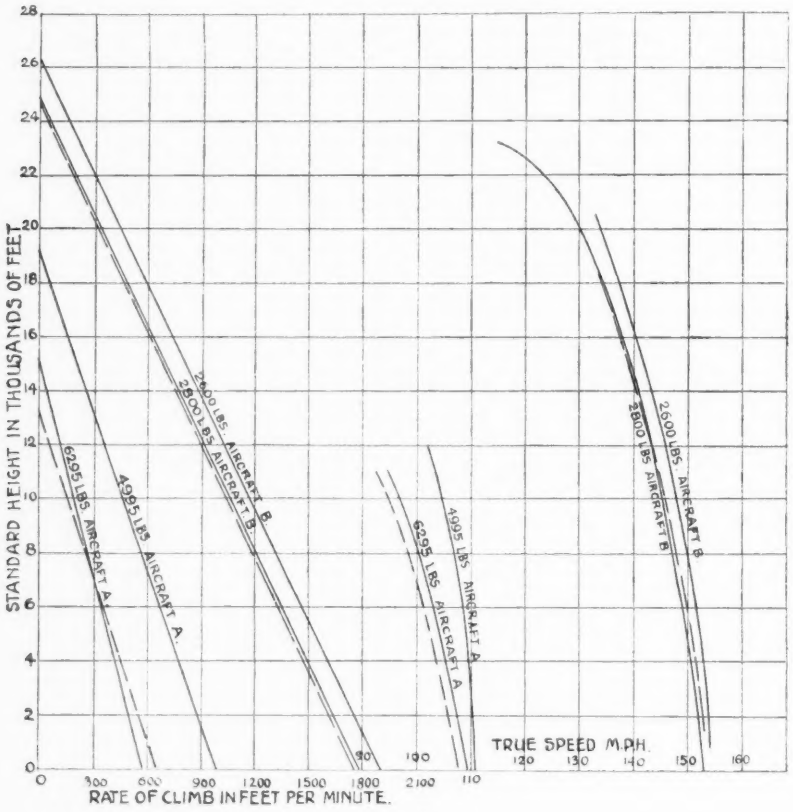
STANDARD HEIGHT IN THOUSANDS OF FEET
RATE OF CLIMB IN FEET PER MINUTE.
TRUE SPEED M.P.H.
2600 LBS. AIRCRAFT B.
2800 LBS. AIRCRAFT B.
4995 LBS. AIRCRAFT A.
6295 LBS. AIRCRAFT A.

FIG. 8.

Change of Performance.
With Change of Total Flying Weight.

——————— Performance by Tests.
— — — — Predicted Performance.

to be in satisfactory agreement with tests curves at that weight, in view of the fact that the density law was used for the reductions and the test instruments were not calibrated for temperature.

(5) The possibility of plotting values of the primary variables in a two-dimensional diagram in which the curves are unaltered by change of linear dimensions, wing loading and air density depends, as was stated above, on the effects of the secondary variables being inappreciable. Conversely, if such a diagram applying to a particular aircraft is unaltered under all possible conditions by a change of wing loading, air density and air temperature, the effects of the secondary variables must be negligible. This suggests obvious tests to detect the presence of effects of the secondary variables.

The foregoing statements appear to embody all the information obtainable from considerations of the dimensions only of the quantities involved. They are unaffected by the form of the equations of motion, and it would appear that they should therefore be applicable to the autogyro as well as to the aeroplane. In view of their wide generality and the essential accuracy of any conclusions derived by their use—provided effects of secondary variables are negligible—they are very valuable.

A preliminary description of the method employed at Martlesham for the further analysis of performance has been published.* Several alternative schemes were proposed, some involving approximations introduced to reduce the amount of computational work involved. It has been found, however, that the advantages of retaining the strictly accurate form more than outweigh the not very considerable additional time required for the computations and it has therefore been decided to abandon the approximate methods. Some modifications have, moreover, been introduced. The method will now be described briefly in the form which has been finally standardised for research tests at Martlesham.

The analysis is based upon a particular case of the two-dimensional diagram with primary variables or functions of them as co-ordinates, to which reference has already been made. In this case the co-ordinates chosen are:—

Abscissa.—The component of the total aerodynamic force on aircraft and airscrew, resolved along the airscrew axis and divided by $S\rho V^2$, where S is the wing area.

Ordinate.—The logarithm of the component at right angles to the airscrew axis of the total aerodynamic force divided by $S\rho V^2$.

The logarithm is used in the case of the ordinate partly to give a more convenient scale for the ordinates and partly to aid further analysis, as will be seen later.

The chosen co-ordinates may be shown to be functions of the primary variables, and we have seen that families of curves representing constant values of the primary variables may always be plotted in a diagram in which co-ordinates of this type are used. The families required for the analysis are:—

(1) Curves representing constant values of $V\sqrt{(\rho/w)}$.
(2) Curves representing constant values of the angle ϕ of the airscrew axis to the horizontal.
(3) Curves representing constant values of V/nD.
(4) Curves representing constant values of incidence ψ.

It can be shown that curves (1) and (2) are the same for all aircraft when the particular co-ordinates selected are used. A basic diagram (Fig. 9) may therefore be prepared on which are plotted these two families. By means of such a diagram, if the indicated air speed is read on a flight, and the inclination

* R. & M. 985.

of the airscrew axis to the horizontal ϕ, by means of a spirit level or pendulum, the point corresponding to the conditions of flight may be plotted in by reference to the two families of curves, and the abscissa and ordinate of the point specify the aerodynamic force coefficients on the aircraft *and airscrew* for the components of the total aerodynamic force along and perpendicular to the airscrew axis.

It is next required to plot in on the basic diagram curves (3) and (4), *i.e.*, curves of constant V/nD and constant incidence. To do this a number of throttled flights, more fully described later, are carried out at each of a series of indicated air speeds. The throttle settings are varied at each air speed so that for each indicated air speed several values of airscrew rotation rate n and attitude angle ϕ are obtained. From these data we may calculate V/nD for each flight and by a system of cross plotting which I need not describe in detail a series of values of ϕ and $V\sqrt{(\rho/w)}$ is obtained for several selected values of V/nD. From these the curves of constant V/nD may be plotted in by reference to the families of curves of constant ϕ and constant $V\sqrt{(\rho/w)}$. For the constant incidence curves, the rate of climb V_c is obtained on each of the throttled flights which give the data for plotting the constant V/nD curves, and from this the angle of climb θ is evaluated by use of the formula $\sin\theta = V_c/V$, and then the incidence ψ from the formula $\psi = \phi - \theta$. A cross plot similar to that used for the constant V/nD curves enables values of $V\sqrt{(\rho/w)}$ and ϕ to be obtained for several selected values of incidence, and from these the constant incidence curves are plotted. The incidence curves in Fig. 9 are semi-diagrammatic, as the tests to fix their position accurately have not yet been completed. Having obtained in this way the two additional families of curves we may immediately obtain from the diagram the values of the components of the total aerodynamic force along and perpendicular to the airscrew axis corresponding to any given values of V/nD and incidence. The force components divided by $S\rho V^2$ we may call the total force coefficients, for brevity. Both are functions of V/nD as well as incidence; that for the component along the airscrew axis because the component includes thrust and the slipstream effect on drag; that along the perpendicular because it includes slipstream effect on lift.

Before passing to the method of separation of each force coefficient into the parts depending on V/nD and incidence, it is of interest to note what would be the characteristics of the diagram (Fig. 9) if there were no slipstream effect on lift or drag.

If there were no slipstream effect on lift, the incidence curves would clearly be lines parallel to the axis of abscissæ; for the force coefficient for the component perpendicular to the airscrew axis would depend on incidence only. The force coefficient would, in fact, be the lift coefficient to body axes for the whole aircraft, usually denoted by k_y. It is convenient to continue to denote the force coefficient by k_y when slipstream effect on lift is present; in that case k_y is a function of V/nD as well as incidence, and the incidence lines are no longer parallel to the axis of abscissæ.

If there is also no slipstream effect on drag, then the constant V/nD curves must be superimposable by translation parallel to the same axis; for in that case, by the well-known equations of steady flight of an aircraft, the abscissæ become $(D^2 S)(V/nD)^{-2} k_T - k_x$, or for brevity $T - k_x$, where T varies with V/nD only, and k_x, the overall drag coefficient, varies with incidence only. Hence the difference between the abscissæ of points on two V/nD curves for which the ordinate has the same value is $T_1 - T_2$, for k_x must be the same for both since k_y is the same. A mere inspection of the diagram, therefore, gives some indication of the magnitude of the effects caused by the slipstream.

To separate the parts of the total force coefficients which depend on V/nD and incidence when slipstream effect are taken into account, two assumptions

are made. It will be found that both can be checked to some extent by the further analysis. It is assumed that :—

(1) The ratio of the resistance of the parts in the slipstream to the resistance of the same parts in the relative wind outside the slipstream is given by the

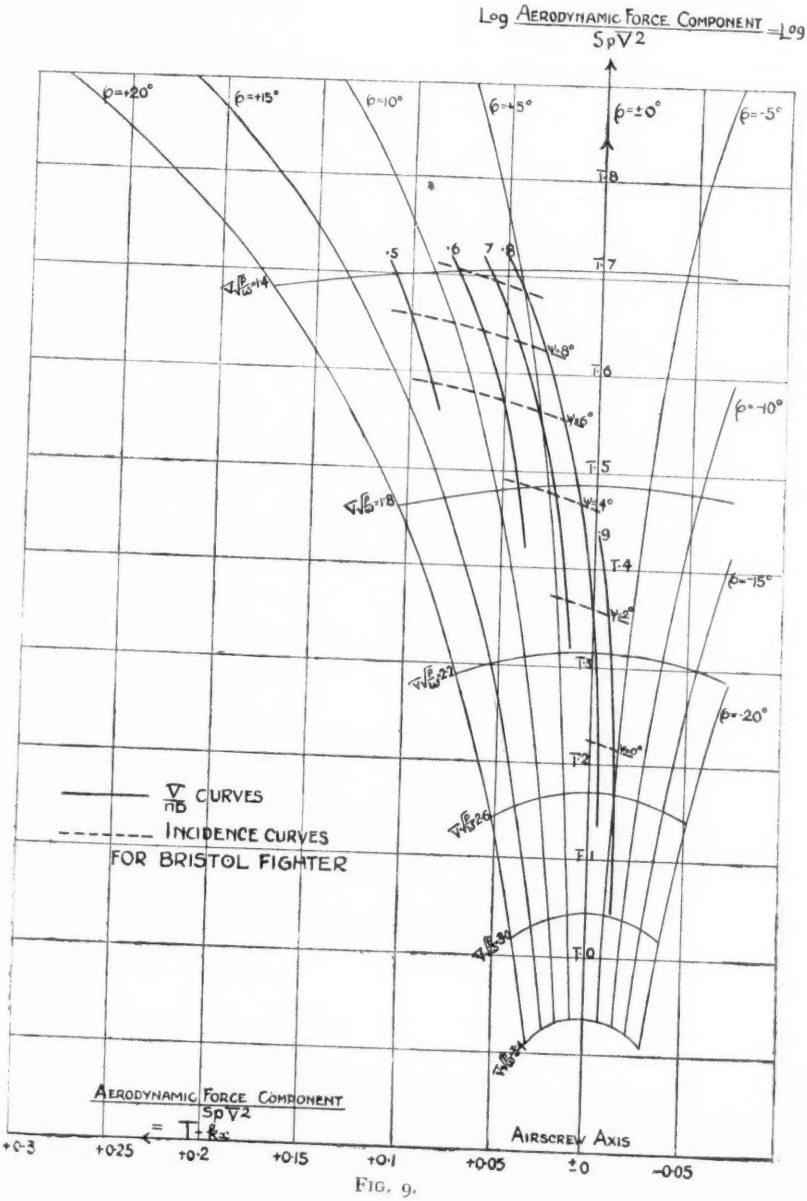

FIG. 9.

well known formula $a_1 + a_2$ (Thrust$/S\rho V^2$) where a_1 and a_2 are constants. This formula was used by Professor Bairstow and Dr. Coales* for the same purpose.

(2) The coefficient k_y of the total aerodynamic force perpendicular to the aircraft axis is the product of two functions, one depending on V/nD only and the other on incidence only. Evidence for the approximate validity of this

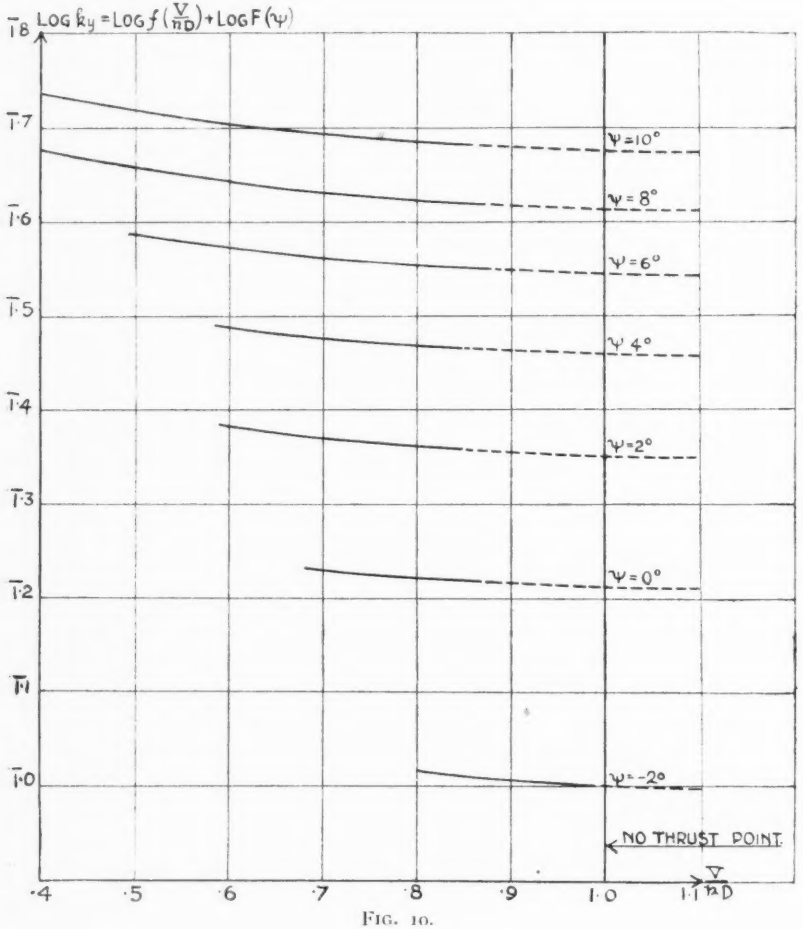

FIG. 10.

assumption is contained in Mr. Relf's 1/5th scale model tests of a Bristol Fighter.† We may therefore write

$$k_y = f\,(V/nD)\,F\,(\psi).$$

It is of interest to note that the two assumptions lead to the same form for the ordinates and abscissæ of the reduction diagram (Fig. 9) when log k_y is

* R. & M. 474.
† R. & M. 937.

used as ordinate, viz., each is the algebraic sum of two terms, one depending on V/nD only and the other on incidence only.

To separate the components of k_y a fresh diagram is prepared (Fig. 10) by plotting the values of $\log k_y$ for the points where the constant incidence curves in Fig. 9 cut the V/nD curves against the corresponding values of V/nD. If the assumption as to the form of k_y is correct, the constant incidence curves in the new diagram will be superimposable if transposed parallel to the $\log k_y$ axis. For if ψ_1 and ψ_2 are the values of ψ for two of the incidence curves, then the difference between any pair of ordinates of these curves for which the value of V/nD is the same is $\log F(\psi_1) - \log F(\psi_2)$ and this is constant along the curves. Hence, if our assumption as to the form of the overall lift coefficient is correct, the incidence curves in Fig. 10 must be superimposable. The check is not altogether satisfactory, however, as the curves do not overlap except along a part of their length owing to limitations imposed on the test data by the maximum permissible airscrew rotation rates and the minimum at which a steady reading of the tachometer is obtainable. Assuming their superimposability we may produce them, as shown by the broken lines in Fig. 10, to cut the vertical line drawn through the value of V/nD for which $f(V/nD)=1$, *i.e.*, the value corresponding to no slipstream effect on lift, and therefore to no thrust. This value is not determinable from performance tests, and in fact cannot be obtained without a thrustmeter, but as an error of as much as 0.2 in its value probably introduces an error of less than 1 per cent. in the overall lift coefficient, k_y, it can no doubt be estimated with sufficient accuracy. From the intersections of the incidence curves with this vertical line we may now read off $\log F(\psi)$ for various values of ψ, and finally plot $F(\psi)$ against ψ, the final curve giving the lift coefficient free of slipstream effects on lift. The relationship between $\log f(V/nD)$ and V/nD is given by any one of the incidence curves of Fig. 10, measuring the ordinates from the value of the ordinate at the intersection of the incidence curve and the vertical line through the value of V/nD for which $f(V/nD)$ is unity.

In Fig. 11 is shown the slipstream effect on lift obtained from air tests on a Bristol Fighter similar in all respects to that used by Mr. Relf in the 1/5th scale

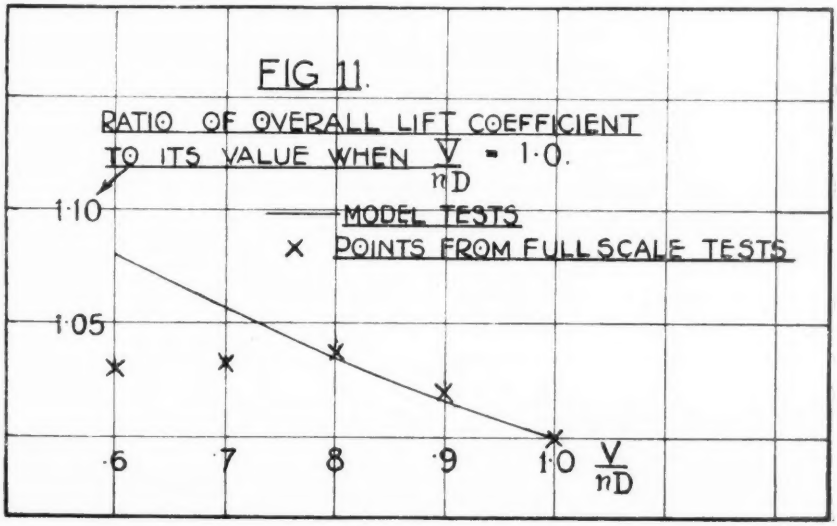

FIG. 11.

model tests. The full scale tests show a definite increase of lift due to slipstream, but the amount is not in very good agreement with the model tests, probably because it was not possible to devote sufficient time to the air tests to ensure that the effects of vertical currents were eliminated in the mean.

To separate the contributions of thrust and drag to the aerodynamic force along the airscrew axis, the first assumption is used. Following the argument of the authors named, the slipstream effect on drag may be included if the drag and thrust coefficients are modified slightly, and the abscissæ remain therefore in the form $T-k_x$, where T and k_x depend on V/nD and incidence respectively.

A diagram (Fig. 12) is now drawn out, similar to that used to separate the components of k_y. The constant V/nD curves of Fig. 9 are re-drawn in it to co-ordinates ψ and $T-k_x$ and by a precisely similar argument to that used in the check of the second assumption, we find that if the first assumption is correct these curves are superimposable by translation parallel to the $T-k_x$ axis. The same difficulty, due to the limited overlapping of the curves, prevents a complete check in this case also, however.

The separation of T and k_x proceeds by an analogous method to that used for the components $\log f(V/nD)$ and $\log F(\psi)$ in $\log k_y$; but unfortunately in this case it is necessary for their complete separation that the value of V/nD for zero thrust must be known quite accurately if sufficient precision is to be obtained in the final results. It will be found that if this value of V/nD is unknown, it is necessary to include an unknown constant C in the final results. Curves representing k_x+C plotted against incidence and $T+C$ plotted against V/nD may be given, and it is considered preferable to leave the constant in the final data pending the discovery of a satisfactory method of obtaining it rather than attempt to eliminate it by making assumptions which may contain errors of an unknown amount. The designer may then, if he wishes, estimate its value by the use of generalised airscrew curves or by any means at his disposal, and will at least be fully aware of the extent of the risks to accuracy resulting. It is worthy of note that a reliable thrustmeter capable of reading zero thrust at the airscrew axis would enable it to be determined.

Summing up, the reduction will enable data to be supplied represented by the following curves:—

k_y at zero thrust
k_x+C } plotted against incidence.

$f(V/nD)$, the slipstream effect on lift
$(D^2/S)(V/nD)^{-2}k_T+C$ } plotted against V/nD.

In addition, if the engine power at ground level is known with sufficient accuracy, the following data may be obtained from full throttle tests which will be described later by a well-known method believed to be due to Captain G. T. R. Hill*:—

k_Q, the torque coefficient plotted against V/nD.
f, the engine power factor, plotted against standard height.

Nothing has been said as to the estimation of performance by the methods described. There are several obvious ways of obtaining the maximum rates of climb and level speeds from the data provided by the tests required for the analysis, and from the full throttle tests at several heights required for the determination of k_Q. From the rates of climb V_c measured on the tests, for example, $V_c\sqrt{(\rho/w)}$ may be calculated, and by a similar system of cross-plotting to that required to enable the curves of constant V/nD to be drawn in Fig. 3, curves of constant $V_c\sqrt{(\rho/w)}$ may be added to that diagram. Full throttle curves may also be drawn in for the three or four heights at which the full

* T.1929.

throttle tests described later are carried out, by plotting the points defined by the values of V/nD and $V\sqrt{(\rho/w)}$ calculated from the data supplied by the full throttle tests, using the curves of constant V/nD and constant $V\sqrt{(\rho/w)}$ in Fig. 9 to define the positions of the points. As these curves are not required in the analysis with which we are mainly concerned they have not been included in that figure. From the full throttle and $V_c\sqrt{(\rho/w)}$ curves the points on the

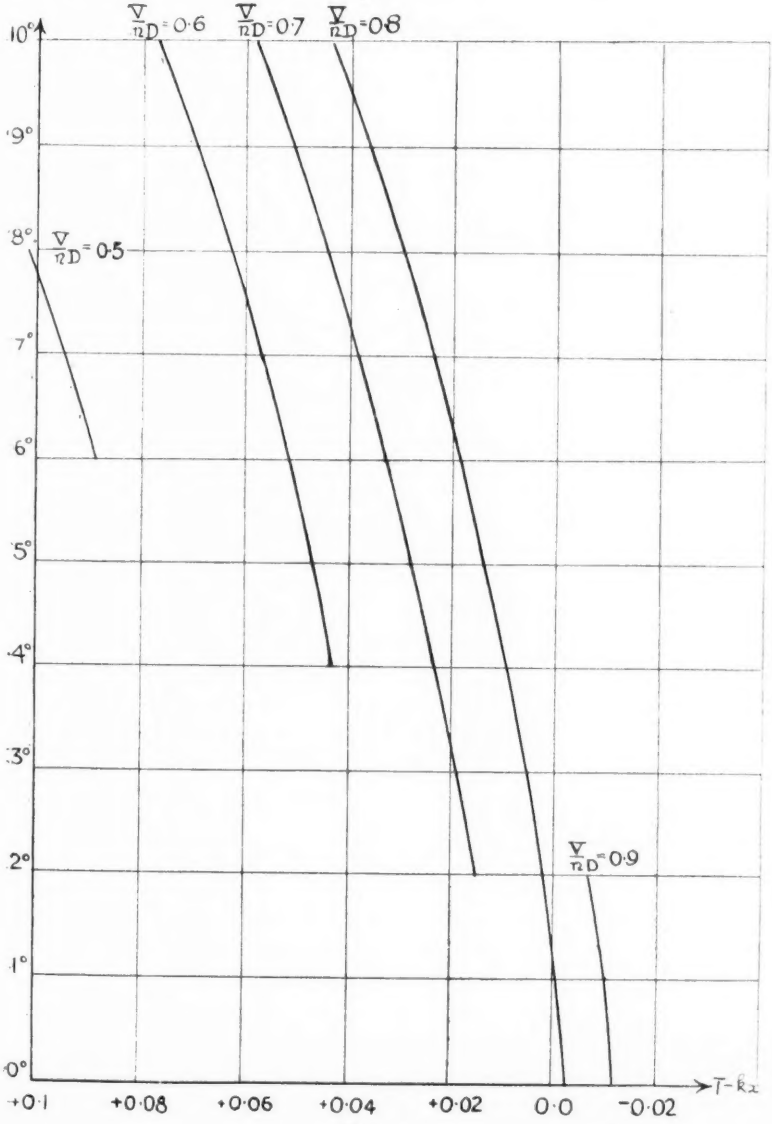

FIG. 12.

full throttle curves for which the values of $V_c\sqrt{(\rho/w)}$ are a maximum may be selected, and the values of $V\sqrt{(\rho/w)}$, $V_c\sqrt{(\rho/w)}$ and V/nD for the points read off (by interpolation) from the appropriate sets of curves. As ρ is known for each full throttle curve, the maximum rate of climb and the corresponding air speed and airscrew rate of rotation may be obtained for each height and plotted against standard height. Smooth curves through the resulting points give the required information as to climb. In the same way, from the points of intersection of the full throttle curves and the zero climb curve $V_c\sqrt{(\rho/w)}=0$ the level speed data may be determined. In Fig. 13 is shown the type of agreement obtained between the new and standard system of tests. Appreciable disagreement could only result either from errors in the tests or from the occurrence of appreciable effects of the scondary variables.

If there is any reason to suppose that noticeable effects of secondary variables are present, as might be the case, for example, if the airscrew tip speeds were very high, a check of some of the throttled tests at a mean height as different as possible from that of the original tests would be carried out. If the points resulting from the check flights plotted in their correct positions on the curves resulting from the original tests, it might be assumed that such secondary effects were negligible. To check the presence of one of the secondary variables (E, ρV^2) a test at another wing loading would be required. Up to the present no noticeable effects of secondary variables, *i.e.*, twisting of the airscrew, air compressibility, or scale speed effect have been observed.

The complete analysis of performance is frequently not required, and from the standpoint of the type of work done at Martlesham, the adaptability of the system to shortening the time required for certain tests, and its use in providing a means of carrying out some special tests, frequently with greater accuracy than would be obtained by the present standard system, is of particular interest. Some of these applications will now be described.

The diagram of Fig. 9 being a particular case of the general non-dimensional diagram, is unaffected by a change of total weight, and if full throttle curves are plotted on it they are also unchanged if the engine power varies with airscrew rotation rates as n^3. In such a case, therefore, performance at any load can be derived immediately without further tests, by merely re-labelling the full throttle curves with a new density obtained from the original densities by a formula given at an earlier stage of this lecture. But if the engine power cannot be represented by the expression with sufficient accuracy, a fresh set of full throttle tests is required at the new load, involving about one hour flying time. Little or no additional flying time is required, therefore, in the frequent cases where performances at several loads are required. Alternatively, the formulæ of the "principle of equivalence," which obviously give the same results, may be used. By the present standard system, a complete new set of air tests is required at each load, involving about five hours flying time.

When it is required that the performance of an aircraft should be obtained with several airscrews, differing slightly in their characteristics, it is only necessary to carry out, with the second, third, etc., airscrews a few air tests to enable the spacing of the V/nD curves to be re-arranged, for unless the change of characteristics of the airscrews is very great, the shape of the V/nD curves and the shape and spacing of the constant incidence curves will be unaltered. A new set of full throttle curves is also required with each airscrew and the new performances may then be predicted immediately. As an example of this, tests of a standard Siskin were carried out and reduced by the methods described. Subsequently, another aircraft, of the same type, was received fitted with a supercharged engine and, of course, a different airscrew. About one and a half hours flying was done to enable the curves to be modified as indicated. Fig. 13 shows the agreement of the predicted rates of climb and speed, and the rates of

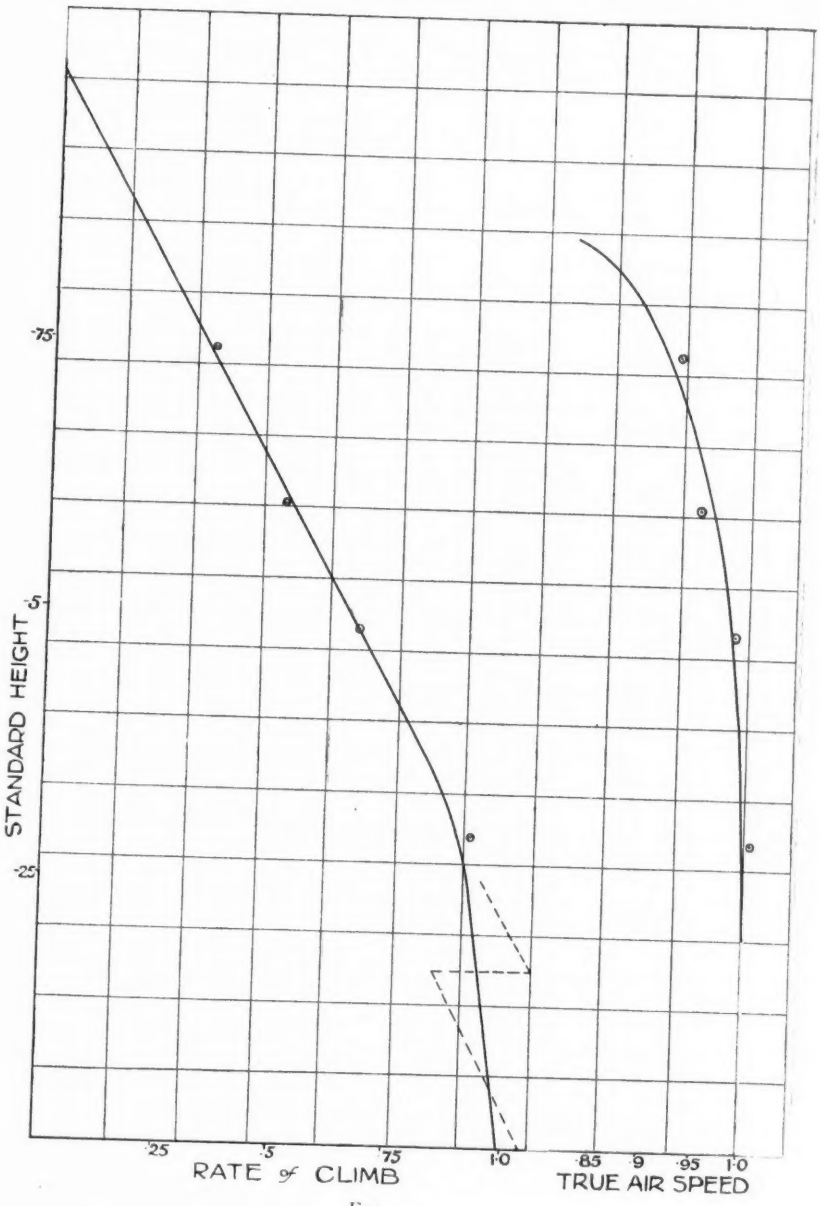

FIG. 13.

Predicted Performance of Aircraft with Supercharged Engine.

Rate of Climb and Speeds by Standard Tests ————————
Predicted Points by New System of Tests ⊙
Part of Climb Curve by New System — — — — — —

climb and speeds found subsequently by the present standard system of tests, for which at least five hours flying time would be required. Conventional height, rate of climb and speed scales have been used as the performance figures have not yet been freed for publication. It is interesting to note that the sudden break in the rate of climb which occurs when the engine is opened up fully with this type of supercharger is not shown clearly by the standard tests, but is fully brought out by the new system. As the second aircraft, though of precisely of similar form, was not actually the same machine, the results show either an element of good luck or excellent standardisation in this type.

Tests intended to show the effect of small changes in the external form of an aircraft are very suitable for reduction by the methods described. For example, if it is desired to determine the loss of performance due to carrying bombs externally, the tests and reduction would be carried out for the aircraft with the bombs, or an equivalent load, carried internally. The bombs would then be attached to their carriers and a few tests done at a convenient value of V/nD to determine the displacement due to the change of k_x of the curve in the reduction diagram (Fig. 9) to which that value of V/nD applied. Since the effect of the bombs is merely to add a constant term to k_x all the V/nD curves must be displaced equally; and since their presence does not affect any other coefficient or the incidence or full throttle curves, the performance when they are carried externally may be predicted at once. It will be noted that vertical atmospheric currents, probably the chief source of error in air tests, do not affect the comparative performances, for they influence the incidence only, and the same incidence curves are, of course, used for both predictions. There would be far less likelihood of detecting the effects of the probably very small difference of drag resulting from the presence of the bombs by the present standard methods since both performances would be affected by vertical atmospheric currents, and it would be improbable that the effect on both would be the same. These examples are sufficient to show the applicability to special problems of the tests and methods of reduction I have described, and the economy in flying time and, in some cases, the increased accuracy which might be expected to result.

It remains only to compare the relative advantages of the new system of tests with the standard system with particular reference to obtaining performance data. But before doing this it is desirable to describe a little more fully the air tests required by the new scheme. These are conveniently divided into:—

(*a*) Throttled tests, which give the fore and aft attitude (ϕ), rate of climb V_c, speed V and airscrew rate of rotation n, at a mean air density ρ, *i.e.*, the data to enable Fig. 9 to be prepared.

(*b*) Full throttle tests, which give the speed V and corresponding airscrew rate of rotation n, at several heights, *i.e.*, for, say, four air densities. These are required to enable k_0 and the engine power factor, f, to be determined. They also enable the performance at full throttle to be specified as has been explained.

The tests (*a*) may be carried out at any convenient height or heights, and are therefore not liable to the same interruptions due to weather conditions as occur in the case of the standard tests, in which satisfactory conditions from the ground to the ceiling are required for each flight. Moreover, it is not essntial for tests (*a*) that the engine should be delivering full power, and the completion of the tests is therefore less liable to postponement through small defects in engine running. About four hours flying is required for a complete set if performance figures and rough aerodynamic data are required. If accurate aerodynamic data are required over the whole possible ranges of incidence and V/nD, about 11 hours must be devoted to these tests.

The procedure is as follows. The pilot is given a set of indicated speeds covering the flying range. He climbs at nearly full throttle from any convenient

height through about 1,000 ft. at the first indicated air speed, and takes a stop watch time, and notes the airscrew rotation rate and air temperature. The angle ϕ may be read by an observer by means of a level mounted in the aircraft, but a self-recording inclinometer has now been supplied by R.A.E. which will provide a more convenient means of obtaining this angle. After the first 1,000 ft. he changes to the second air speed and obtains a second set of figures, and similarly for the third, etc., air speeds. This is repeated at three or four throttle settings. The tests are, therefore, simple and impose no greater demands on the pilot than the present standard tests.

For the full throttle tests, the pilot merely notes the airscrew rates of rotation at full throttle at several selected heights and at several indicated air speeds. Satisfactory weather conditions up to the service ceiling are of course required, and the engine must be delivering full power. For the whole set about one hour is required.

The tests for the standard system are well known. They consist of partial climbs, usually at two heights and three climbs and sets of speeds, with about five speeds in each set. The whole set of tests requires about five hours flying time, if no engine defects or other interferences occur.

The relative advantages of the new and standard system of tests may now be compared, in respect of accuracy and speed with which results may be obtained.

1 *Accuracy as Affecting Estimation of Performance*

Inaccuracies might occasionally occur by the standard system for the following reasons.

Only a limited amount of flying time—say two hours—can be given to partial climbs, *i.e.*, about one hour at each of the two heights at which the partial climbs are normally carried out. The time available does not enable sufficient points to be determined on a partial climb curve to ensure that a mean curve will be obtained which will have eliminated the effects of vertical atmospheric currents, and this will result in the selection of a speed for maximum rate of climb which may actually give a rate appreciably below the maximum of which the aircraft is capable. The other partial climb and the climbs and speeds give no check of this of course, and the error therefore would find its way into the final test results.

In the new system, on the other hand, none of the curves are affected by vertical currents except the incidence curves, for the rate of climb is only used in obtaining incidence. Moreover, as the incidence curves are superimposable, when plotted as in Fig. 10, all the points defining incidence, obtained from about three hours' flying, may ultimately be plotted upon one curve, and there should therefore be a far better chance of eliminating the effects of vertical currents.

The speeds also are rather seriously affected by vertical currents in the standard tests. An error of the order of two m.p.h. may result from an up or down current of only 1.5 feet per second. The probability that all the three speed tests normally carried out at each height may be affected in the same sense is rather high, and such an occurrence would of course again be liable to pass undetected. In the new system, the use of the superimposable incidence curves again gives a high probability of eliminating the effects of vertical atmospheric currents.

2 *Time Required for Completing a Set of Performance Tests*

The actual flying time required for the new and standard tests is about the same, but owing to the less likelihood of interference due to weather conditions in the case of the new tests, following on the fact that the throttled tests, which

take up about four hours of the total flying time, may be carried out at any height where the weather is suitable, less delay will probably occur than in the case of the standard tests, for which good weather conditions from the ground to the service ceiling are essential throughout. The delays sometimes caused by small engine defects reducing the engine power slightly and so necessitating the discontinuance of the standard tests until repairs have been effected will also be less likely to occur in the new system, as full engine power is only essential for the full throttle tests, which take up one hour only of the total flying time.

3 *Other Considerations*

If all aircraft delivered for test were perfect in all respects as regards engine and structure, there would appear to be no advantage in retaining the standard system. It is very desirable in practice, however, that such matters as the efficacy of radiators and cooling water systems, the suitability of the altitude control, and the effects on the aircraft structure of the continued vibration which occurs on a long climb at full throttle should be investigated and that any faults of the type indicated should be discovered at the earliest possible stage in the tests in order that steps for their rectification may be taken. Climbs at full throttle provide the best and probably the only satisfactory means of detection of such faults. Moreover, reduction by the new system requires considerably more computation than in the case of the standard tests, and as the results on the first experimental aircraft of each type are usually required with the minimum delay, the small loss of time which might result becomes important.

It seems probable, therefore, that the most satisfactory procedure will be to test the first experimental aircraft of a type by the standard system of tests, and to carry out the new system at a later stage on the second experimental aircraft, or on the first when it again becomes available for re-allotment to Martlesham. A little delay would be caused if this course were followed in providing the designer with the detailed aerodynamic information furnished by the new system of tests, but it is considered preferable that this should occur rather than that there should be any risk that such defects as inadequate cooling arrangements should pass undetected in the original tests. The present position at Martlesham is as follows:—A few aircraft are being selected from new types received for test, and at some stage subsequent to the initial performance tests by the present standard system these aircraft will be returned for tests by the research section at Martlesham on the new scheme. When further experience has been obtained, it may be desirable, in view of the less likelihood of errors and the probably reduced time required with the new system, to request the Air Ministry to authorise the extension of the new system to development tests, with the proviso that the initial tests will probably invariably be carried out by the present standard methods, for the reasons given in (3).

The formulation of a satisfactory method of determining the constant C which occurs with the drag coefficient is the chief feature on which further work is required. Until this constant can be determined with the requisite accuracy, the analysis certainly loses much of its value to the designer. The difficulty is not peculiar to the present system however, but can easily be seen to be fundamental and must really occur in any analysis which is based purely on full-scale tests without any special device such as a thrustmeter. It is thought that in spite of this lacuna in the data provided by the analysis, the results of the analysis cannot fail to be of value to the designer, as providing him with all the information available in the present state of development of aircraft testing free of any inaccuracies which might result from approximations and assumptions unchecked by the tests, and to the aircraft tester, as giving him a means of carrying out many special tests, such as the tests of an aircraft with several airscrews, with increased facility and in many cases with increased accuracy.

Discussion

Sir Sefton Brancker: I frankly confess that I had not realised that the practical testing of aircraft involved such high technical knowledge.

I should like to know the reason of the variation of the altimeter owing to cold.

I should also like to know whether there is any standard system of testing throughout the world. If not, the F.A.I. or I.C.A.N. ought to be approached regarding the necessity of establishing a standard system.

Mr. H. E. Wimperis: I have listened to Mr. Capon's paper with great interest, and I have been much impressed by it.

Mr. Capon has had a very difficult task to perform. Nine years ago, when Mr. Tizard initiated performance testing at Martlesham, he devised the system which remained in force for many years. In the passage of the years there have been some alterations in the system, not in principle but in detail. The effects of temperature change now lead to difficulties which we were not troubled with nine years ago, for it can be noticed on the curves the lecturer has shown to-night that discrepancies get really serious as the temperature sinks to $-30°$ or $-40°$.

Another kind of change that has taken place in the nine years is in the volume of work with which Martlesham has to deal. It increases every year, owing to the growing activity of the constructors in producing new types. With this enormous amount of work to be carried on without loss of time every effort has to be made to get the maximum amount of information from the tests made. Every advantage should be taken of the best methods known to science. Mr. Capon has told us of a successful method he has devised whereby the amount of information obtained is greatly increased.

Some of those who have heard the lecture and read the paper, but who have had no experience of the tests that have been made to test the theory, may say: "This is very novel and striking. I wonder if it is correct." I may therefore say that the method has been scrutinised by the experts of the Aeronautical Research Committee, who have given it a "clean bill of health."

We are very much indebted to Mr. Capon for bringing the paper before us, and I should like to bear witness to the very efficient work he has done at Martlesham during the past two years.

Mr. R. McKinnon Wood: I first came across the method of performance analysis that has been described to-night some months ago in a paper the lecturer had written on the subject, and having mastered the method of analysis, I was forced to ask myself what it was really worth, for one comes up against constant C which is unknown. I want to make a suggestion to Mr. Capon for a method of obtaining that constant, a method originated by Dr. Stanton a considerable time ago, of measuring thrust by means of a pitot tube. The actual instrument I propose would take the form of a streamlined tube, mounted radially behind the airscrew, into which would lead a series of small pitot tubes located at the mean radii of anuli of equal area. The pressure in this tube would be the mean of the pressures in all the pitot tubes and would give the thrust. This would not perhaps make a good thrustmeter for large thrusts; but for measuring zero thrust it should be quite good. It would be the simplest instrument to make and manage.

I asked myself, if the constant C is unknown, what is the value of the analysis? One of the particular advantages is that one always gains a great deal of accuracy in experimental work by studying the subject by analytical methods.

Apart from that, the author has indicated a number of other advantages. One is the prediction of change of performance with change of weight. As a matter of fact, that does not require all the analysis of the paper, but, as Mr. Capon has shown in a paper he has written, that can be done more simply. He has also shown us how one can obtain the effect on performance of changing airscrews in an aeroplane without going through the whole performance with each airscrew.

I suggest another application of the method of a similar nature—that in testing a number of aeroplanes built with the same engine to the same specification, it would not matter if all the engines were up to power, provided that one engine gave the correct power and all the aeroplanes were tested with the same airscrew as well as with the airscrew provided with each aeroplane.

Turning now to a rather different point in performance testing, it seems to me that there are two main causes of error. One is due to uncertainty as to whether the engine is giving its full power according to the test bed figures. At present all that is known is the A.I.D. test of the particular engine at the maker's works. I suggest that a test fan might be used to calibrate the engine on the ground in the aeroplane. I believe that reliance could be placed on such a test, and its introduction would increase the value of the results.

The second main cause of possible error is up and down currents. These are a particular difficulty at Martlesham, where, owing to the urgency of the work, one cannot wait for good weather conditions before making a test as at Farnborough, nor can one spend so long over it. To eliminate this error we require to measure incidence. In order to be able to measure incidence in flight one must get away from the aeroplane to where the flow is not disturbed by it. We have been experimenting with an incidence meter suspended underneath the aeroplane at a distance of 100 feet. This method is now coming into use for research purposes, and I hope to see it in use for routine test purposes soon.

There is one other minor point I should like to make, and that is an objection I have to the use of the term "lift to body axes." It would be much better to call it the "normal force," because it is bound to lead to confusion if the terms lift and drag are used in any other sense than to express forces at right angles to and along the direction of motion of a body through a fluid.

I should like to thank the author for an extremely interesting paper.

Mr. HANDLEY PAGE: We are particularly indebted in the industry to Mr. Capon because his method gives aircraft constructors and designers a method of testing without necessitating four or five hours' flying. This often entails waiting for suitable weather between each flight, when one is in a hurry to get a machine tested and away. His method simplifies the performance testing and enables us to get records in a simple way.

I should, however, like to utter a word of caution. However much one may endeavour to cut down the amount of testing required, one must have a full climb to ceiling, and an opportunity to find out a machine's structural weaknesses (if any). When comparing machines, by means of these curves, we consider two machines, for instance, perhaps comparable one with another as to absolute coefficients, but in that reduction we have completely eliminated weight. In this way one might appear better than the other, whereas, in fact, its weight being much greater, its actual performance figures would be worse. I think when one comes to making one's final comparison, one has eventually to get back to comparing them with the actual weight, speed, and so forth, and not only by the relative aerodynamic characteristics we have been shown.

The author with this paper has set the final seal on the testing method commenced by Tizard and Coates.

Squadron Leader T. H. ENGLAND: I should like to say that as a means of performance testing the method evolved by Mr. Capon has one very great point, *i.e.*, in time of war, when time is everything.

The great difficulty in a testing establishment is to get reliable and consistent pilots, and then you have to study them and allow for their idiosyncrasies. In time of war it is difficult to pick your test pilots and retain them. This is where this method comes in. It takes no time to carry out and 90 per cent. of the work is done on the ground by the technical staff, who supply the pilot with certain details such as r.p.m., flying speeds and heights at which to fly. The duties required of the pilot are few and extremely simple to carry out, and in my own opinion, as a result of experience of both methods, I would far rather work to Capon's method than the orthodox system, simply because in Capon's method one is only called upon to concentrate for periods of about three minutes, whereas in the old method it might mean anything up to fifty or more minutes' solid concentration on four to six instruments, which tells very greatly on the pilot and I do not consider it to be so accurate.

Major T. M. BARLOW said: We have heard to-night the summary of a paper which I feel sure you will all agree is a very worthy successor to that read by Mr. Tizard nine years ago. It is extraordinarily fitting also that this important addition to the published papers of the Society has been given by the Chief Technical Officer from the Royal Air Force Experimental Establishment, Martlesham Heath, and I feel sure that, as already suggested by the Chairman, this paper will be taken as a model and adopted by other countries as Tizard's method was adopted in the U.S.A. and France in 1918.

I have one or two criticisms to make.

First, the speed course. Whilst agreeing, the new method is as accurate as one can reasonably expect, I do not think the Author has been quite fair to the former method in choosing Fig. 3 to illustrate the comparisons. This shows the old method pitot correction over a speed range of 35 m.p.h. I think if 85 m.p.h. range had been chosen, similar to the new method, a better comparison would have been obtained in so far as the average differences would have been much smaller. He mentions the controlling static pitot tube. Personally, I have not been able to use this for speeds over 100 m.p.h. without difficulty and I should like to know if he has been able to overcome this instrument swinging excessively at high speeds, thus rendering it useless.

The outstanding point of the first part of the paper is the unsuitability of test instruments as regards temperature correction. I see no reason why instrument research should not be able to incorporate temperature compensation in the actual instruments similar to the gear already incorporated in watches and chronometers for the same purpose. This would obviate the complicated temperature corrections which now have to be done. It is regretted that the only instrument illustrated in the paper appears to be of German origin (from the markings) also this instrument is a type which, if it does all that is claimed for it, will be of tremendous use to all those aircraft constructors who carry out their own performance testing.

With regard to temperature correction. We should like to know what difference the Author noted in temperature readings obtained in the cockpit, which is near the instruments, and the atmospheric temperature. Personally, I used to find a very big difference when flying in the sun compared with readings taken when flying away from the sun. This means that the pilot will have to take continual cockpit temperature readings if accurate corrections are to be found on the instrument. In the latter part of the paper the Author described what I call a method of carrying out performance testing in bad weather which I feel sure is going to be a great help to us in speeding up preliminary trials

and I see no reason why this should not be adopted. Incidentally, in describing the test method, he makes no mention of those rather controversial points—lift and stalling speeds. I should like to know whether he can enlighten us on methods to be adopted for determining these with some uniform degree of accuracy. It is certainly vital to know these speeds on aircraft designed for deck landing.

When I first read the proof of this paper I thought the Author had contemplated a complete change in the method of testing, but I note, with approval, in the latter section his scheme is that the aircraft will first be tested by the old standard method and then returned to the experimental station for the complete analytical test he has clearly outlined this evening. I think it very necessary to retain the old standard method as every aircraft constructor likes to say that his machine has been up to 20,000 feet, say, and developed a certain performance there rather than estimate the performance at that height from a test carried out at a much lower altitude.

Mr. COWLIN: I should like to congratulate Mr. Capon on this paper. The part dealing with analysis strikes me as extremely fine, and I do not feel like offering any comments on that, but there are a few points with regard to the earlier part of the paper about which I wish to speak. Firstly, the question of the temperature calibration of instruments. We have been using one of the calibrating chambers at Felixstowe, but we have not perfect confidence in it. There is stratification of the air taking place inside it, giving a difference between top and bottom readings which may amount to 20°. One rather hopes that when this has been overcome it may be found that the temperature difficulty will not be quite so serious as yet appears.

The statoscope of the Askania pattern that is mentioned in the advance proof has not been referred to to-night. At Martlesham they have found that an extremely useful instrument. We have tried it also at Felixstowe, and came to the conclusion that the results to be obtained from it were approximately as accurate as were obtained with the standard altimeter and that both were inferior to the new sensitive type of altimeter developed specially for test work. The Askania instrument is of German make, and internal examination shows it to be hardly up to the standard of what one expects in the best English instruments and does not give the confidence one would desire.

Up and down currents have been mentioned, and there I can give an account of a little experience we have had. We have tried to work in touch with the local meteorological officer, and have had from him reports of local up and down currents at the same time as the tests were going on, but we have not found the differences reflected to any large extent in the test results. The machines, even the low-powered ones, have staggered on apparently very little affected by the currents. It may be that up and down currents are localised. This co-operation with the meteorological officer has led us to the view that there are spots in the neighbourhood where there are currents that are relatively steady. If there are tests to be carried out they are carried out there, and by using these patches of steady current it is possible to eliminate a good deal of uncertainty.

I want to pass now to the very end of the paper. When I first read the paper I felt that we were going to find a recommendation of an entire change of testing methods, and I was glad to find it was really an addition, because I do feel that however essential it must be from some standpoints to cut down the hours of flying, from other points of view it is desirable to increase the amount of flying, and increase the total amount of time spent by the aircraft at testing establishments. For seaplanes and flying boats this is most important, if one is to have experience of their reliability, care and maintenance points, etc., that only crop up if one carries out a large amount of flying. It may appear that the necessity for the longer time in the case of marine aircraft shows their inferiority to land

aircraft, but it is merely because this branch has been starved for some years and has to catch up. It is an aspect that I think very important, and I was very glad to find that the representatives of the aircraft industry agree that that is so.

Mr. R. K. PIERSON: I have found the paper most interesting; I have a few remarks to make. We have found partial climbs extremely difficult to measure accurately owing to vertical air currents; this is particularly noticeable when climbs are made throttled, owing to the slow rate of climb; to have any success we have found that tests must be made in the early morning before sunrise; on the other hand, in a steady climb, these up and down currents appear to neutralise each other; at any rate, the barograph record is not seriously affected by them.

With regard to engine power at altitudes, we should be very glad to have more information as to the way in which the horse-power height factor varies with compression ratio for various engines.

As to the new method of analysis, until we have applied it to the tests of one or two machines, I cannot say how useful it will be to us. I might mention that when Martlesham tests were corrected with the density assumption, analysis produced very inconsistent results. I am hopeful, however, that the introduction of the pressure method will make more accurate analysis possible.

The AUTHOR, in reply to the discussion, said: It is a very difficult paper to read, and I am very glad to find that in spite of the difficulties there must have been in understanding it, an interesting discussion has come out of it.

The Chairman asked as to the temperature errors in the altimeter. The errors shown in the altimeter readings are apparently simply due to design, because the barograph gives no serious errors at all.

When we consider the international standardisation of tests there is no doubt that the law of variation of power with height will have to be standardised. Martlesham will soon have their contribution to the discussion ready, I think, and it appears probable that tests at that station will indicate a law between pressure and density, but rather nearer the former. It will probably be necessary for the testing and experimental stations in this country to arrive at an agreed law before steps are taken for a revision of the density law at present adopted internationally.

Mr. Wood's remarks would require a paper in themselves in reply. Of course the determination of the constant C is fundamental, for parasitic drag cannot be found without it. His suggestion that a number of pitot tubes should be used was put forward some time ago by Mr. Jennings. I do not know what degree of accuracy can be expected from that method, but it would be a useful thing to try. A thrust meter to record zero thrust would also enable the constant C to be determined, but this method would be less satisfactory owing to the boss effect.

As regards the errors due to vertical atmospheric currents, no doubt the incidence meter will give a very big improvement. Another way of getting over that difficulty is to use a calibrated aircraft, *i.e.*, an aircraft for which Fig. 9 of the paper has been made out, and fly it with the one being tested. They will both be equally affected by vertical currents, and the rates of climb and level speeds of the aircraft under test can then be determined by reference to the calibrated aircraft.

As regards the test fan, I always understood that the test fan was not very accurate, but if it is reliable it would be an excellent thing to test the engine power on the ground before doing the standard tests.

I agree with Mr. Wood that the use of the term lift to body axes is awkward and normal force could certainly be used instead.

Mr. Handley Page spoke about the comparison of aircraft by means of curves representing the values of absolute coefficients. I quite agree that per-

formance figures with the specified load will always be required, and that at least one climb to the service ceiling should always be carried out.

Major Barlow said I was not fair to the old speed course method. I think that the old method was usually accurate, but the occasional errors one found with it are completely eliminated in the new method. The pilot seems to make errors very seldom, but the ground observers occasionally do. The advantage of the new method is not very great, but it avoids a few disconcerting inaccuracies. Automatic methods are used in other countries it is understood, *e.g.*, in the U.S.A., France and Holland, and this country did seem to be rather behind in this respect.

With regard to Major Barlow's remarks as to the oscillations of the suspended static heads at high speeds, such oscillations have been observed at Martlesham at speeds above 130 m.p.h., and in such cases it is necessary to use the speed course.

With regard to the illustration of the statoscope, it just happened that we had that particular instrument for test and retained it for general use. The altimeter was not good for partial climbs because it was obviously very difficult to read ranges of 1,000 feet accurately. Supposing one makes an error of 30 feet at each end in opposite senses, the error amounts to 60 feet in 1,000 feet, *i.e.*, 6 per cent. in the rate of climb. With the Bamberger statoscope one can measure to about 10 feet.

We have compared temperatures within the cockpit and outside and they are about 10°C. higher inside than out. Most test aircraft now carry thermometers on the dashboard. The pilot reads the thermometer on the dashboard now and again so that the temperature of the instruments can be checked.

Stalling speed measurement is very important indeed. The method of measuring stalling speed used at present was suggested by the A.R.C., I believe, or at all events discussed by them. A self-recording airspeed indicator is mounted on the aircraft whose stalling speed is required, and the pilot flies as slowly as he can for a minute. The highest speed recorded is considered the stalling speed. The variation is very small over the minute, generally not more than two miles per hour, unless the machine is unstable. We tried sending up different pilots, but they all got practically the same results.

The landing speed is a debatable point. Are you to measure the speed on the ground or in the air, just before the wheels touch? It is impossible for the pilot to read an indicator at the moment of landing because of the rapid change in the indicated speed. We mounted a self-recording airspeed indicator and the record showed a jerk when the wheels touched the ground. By this method we found one or two miles per hour difference only between the actual speed when the wheels touched and the speed read just before the sudden fall of air speed. The speed just before the wheels touch is therefore used to fix the landing speed.

Mr. Cowlin spoke about stratification in the cold temperature chamber. We have recalibrated the airspeed indicators by putting them into cold petrol and the results are substantially the same. It seems probable, therefore, that the stratification was causing no serious error.

I agree that the more flying one can do when testing machines the better. One wants to get as much flying as possible.

Mr. Pierson mentioned the difficulty of recording accurately on partial climbs owing to vertical air currents. It is only an apparent difficulty, I think, as when a large number of partial climbs are done, as in the new method of performance testing, the effects of vertical currents mean out in the incidence curves. The close agreement of performance predicted by the new methods and check performances by the standard methods show that vertical currents have not a more serious effect on the former than on the latter. In fact, a careful examination of the two methods makes it apparent that vertical currents should be better meaned out in the new methods.

THE ARTICULATED CONNECTING ROD

E. J. FEARN, B.SC. (ENG.).

In the past the usual method of dealing with the articulated rod has been to treat the problem graphically. Although this method may be sufficiently accurate for a first approximation the inherent difficulties often lead to serious errors after the first few stages. A graphical method is always sufficiently accurate to determine the travel of a piston operated by an auxiliary rod; but, the double differentiation of the displacement curve by graphical means (to obtain the acceleration curve), is not only inaccurate but a long and tedious operation.

To remedy this defect a Fourier's series has been developed which can be differentiated at sight and which gives a remarkable accuracy.

The geometrical properties of the mechanism have been analysed and thus equations are formed giving the resultant radial and tangential components at the crank pin, the bending forces and tensions on the master rod, etc.

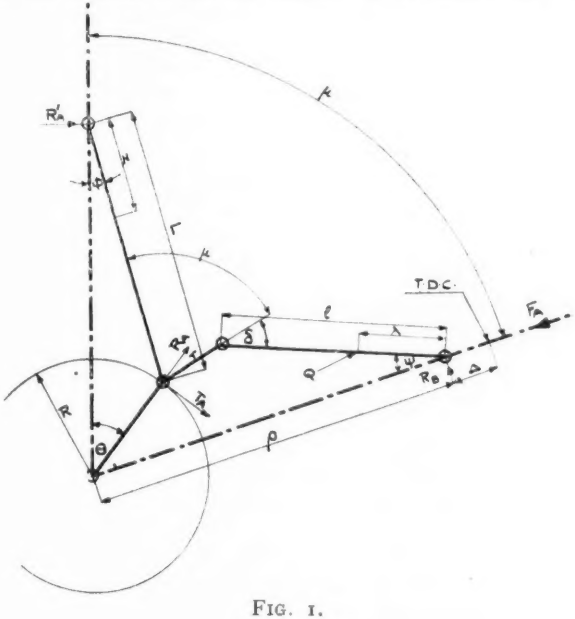

FIG. 1.

Let us assume that the displacement can be expressed in the form of a Fourier's series. If now we calculate the actual displacements, ρ_0, ρ_{45}, $\rho_{90} \cdots \rho_{315}$, when the crank angle θ has the values 0, $\pi/4$, $\pi/2$, etc., then the series representing the curve passing exactly through these eight points is given by

$$\rho = \tfrac{1}{2}a_0 + a_1 \cos\theta + a_2 \cos 2\theta + a_3 \cos 3\theta + \tfrac{1}{2}a_4 \cos 4\theta + b_1 \sin\theta + b_2 \sin 2\theta + b_3 \sin 3\theta \quad . \quad . \quad . \quad . \quad (1)^*$$

* See *A Practical Treatise on Fourier's Theorem and Harmonic Analysis*, A. Eagle, B.Sc., A.R.C.S. (Longmans, Green & Co.)

From the figure it can be seen that

$$\sin\phi=(R\sin\theta)/L \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\sin\psi=[R\sin(\mu-\theta)+r\sin\phi]/l \quad . \quad . \quad . \quad . \quad (3)$$

$$\rho=R\cos(\mu-\theta)+r\cos\phi+l\cos\psi \quad . \quad . \quad . \quad (4)$$

When $\theta=0^\circ$

$$\phi=0^\circ,\ \cos\phi=1,\ \cos\psi=[1-(R^2\sin^2\mu)/l]^{\frac{1}{2}}$$

$$\rho_0=R\cos\mu+r+l\,[1-(R^2\sin^2\mu)/l^2]^{\frac{1}{2}} \quad . \quad . \quad . \quad (5)$$

When $\theta=45^\circ$

$$\sin\phi=R/L\sqrt{2},\ \cos\phi=(1-R^2/2L^2)^{\frac{1}{2}},\ \sin\psi=[R(\sin\mu-\cos\mu)+rR/L]/l\sqrt{2}$$

$$\rho_{45}=R(\cos\mu+\sin\mu)/\sqrt{2}+r\sqrt{(1-R^2/2L^2)}$$
$$+l\,[1-\{R(\sin\mu-\cos\mu)+rR/L\}^2/2l^2]^{\frac{1}{2}} \quad . \quad . \quad (6)$$

Similarly :—

$$\rho_{90}=R\sin\mu+r(1-R^2/L^2)^{\frac{1}{2}}+l\,[1-(R\cos\mu-rR/L)^2/l^2]^{\frac{1}{2}} \quad . \quad (7)$$

$$\rho_{135}=R(-\cos\mu+\sin\mu)/\sqrt{2}+r(1-R^2/2L^2)^{\frac{1}{2}}$$
$$+l\,[1-\{R(\sin\mu+\cos\mu)-rR/L\}^2/2l^2]^{\frac{1}{2}} \quad . \quad . \quad . \quad (8)$$

$$\rho_{180}=-R\cos\mu+r+l(1-R^2\sin^2\mu/l^2)^{\frac{1}{2}} \quad . \quad . \quad . \quad (9)$$

$$\rho_{225}=-R(\cos\mu+\sin\mu)/\sqrt{2}+r(1-R^2/2L^2)^{\frac{1}{2}}$$
$$+l\,[1-\{R(\sin\mu-\cos\mu)+rR/L\}^2/2l^2]^{\frac{1}{2}} \quad . \quad . \quad (10)$$

$$\rho_{270}=-R\sin\mu+r(1-R^2/L^2)^{\frac{1}{2}}+l\,[1-(R\cos\mu-rR/L)^2/l^2]^{\frac{1}{2}} \quad (11)$$

$$\rho_{315}=R(\cos\mu-\sin\mu)/\sqrt{2}+r(1-R^2/2L^2)^{\frac{1}{2}}$$
$$+l\,[1-\{R(\sin\mu+\cos\mu)-rR/L\}^2/2l^2]^{\frac{1}{2}} \quad . \quad . \quad (12)$$

Now in equation (1) it can be proved that

$$^*\tfrac{1}{2}a_0=(1/2p)\sum_{q=1}^{2p}A_q \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$a_n=(1/p)\sum_{q=1}^{2p}(A_q\cos qn\pi)/p \quad . \quad . \quad . \quad . \quad (14)$$

$$b_n=(1/p)\sum_{q=1}^{2p}(A_q\sin qn\pi)/p \quad . \quad . \quad . \quad . \quad (15)$$

where $(\pi/p,\ A_1)$, $(2\pi/p,\ A_2)$, etc., are the successive co-ordinates of the $2p$ points in the period 2π.

Substituting our known values of A_1, A_2, etc. (*i.e.*, ρ_{45}, $\rho_{90}\ldots$ etc.), we have

$$a_0/2=\tfrac{1}{8}\{\rho_0+\rho_{90}+\rho_{270}+\rho_{360}+\rho_{45}+\rho_{135}+\rho_{225}+\rho_{315}\}$$

$$\therefore\ a_0/2=\tfrac{1}{8}\{2r[1+\cos\phi_{90}+2\cos\phi_{45}]+2l[\cos\psi_0+\cos\psi_{90}+\cos\psi_{45}+\cos\psi_{135}]\}$$

where $\cos\phi_{90}$ is the value of $\cos\phi$ when $\theta=90^\circ$, $\cos\psi_0$ the value of $\cos\psi$ when $\theta=0^\circ$, etc.

$$\therefore\ a_0/2=\tfrac{1}{4}\{r[1+\cos\phi_{90}+2\cos\phi_{45}]+l[\cos\psi_0+\cos\psi_{45}+\cos\psi_{90}+\cos\psi_{135}]\} \quad (16)$$

$$a_1=\tfrac{1}{4}\{\rho_{45}\cos\pi/4+\rho_{90}\cos2\pi/4+\rho_{135}\cos3\pi/4+\rho_{180}\cos4\pi/4$$
$$+\rho_{225}\cos5\pi/4+\rho_{270}\cos6\pi/4+\rho_{315}\cos7\pi/4+\rho_0\cos8\pi/4\}$$
$$\therefore\ a_1=R\cos\mu \quad . \quad . \quad . \quad . \quad . \quad (17)$$

$$a_2=\tfrac{1}{4}\{\rho_{45}\cos2\pi/4+\rho_{90}\cos4\pi/4+\rho_{135}\cos6\pi/4+\rho_{180}\cos8\pi/4$$
$$+\rho_{225}\cos10\pi/4+\rho_{270}\cos12\pi/4+\rho_{315}\cos14\pi/4+\rho_0\cos16\pi/4\}$$
$$\therefore\ a_2=r/2\{1-\cos\phi_{90}\}+l/2\{\cos\psi_0-\cos\psi_{90}\} \quad . \quad . \quad (18)$$

$$a_3=\tfrac{1}{4}\{\rho_{45}\cos3\pi/4+\rho_{90}\cos6\pi/4+\rho_{135}\cos9\pi/4+\ldots+\rho_0\cos24\pi/4\}$$
$$\therefore\ a_3=0 \quad . \quad . \quad . \quad . \quad . \quad (19)$$

$$a_4=\tfrac{1}{4}\{\rho_{45}\cos4\pi/4+\rho_{90}\cos2\pi+\rho_{135}\cos3\pi+\ldots+\rho_0\cos8\pi\}$$

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* *Ibid.*

$$\therefore\ a_4/2=\tfrac{1}{4}\{\ r\ [1+\cos\phi_{90}-2\cos\phi_{45}]+l\ [\cos\psi_0-\cos\psi_{45}+\cos\psi_{90}-\cos\psi_{135}]\ \} \quad (20)$$

$$b_1=\tfrac{1}{4}\{\ \rho_{45}\sin\pi/4+\rho_{90}\sin 2\pi/4+\rho_{135}\sin 3\pi/4+\ \ldots\ +\rho_0\sin 8\pi/4\ \}$$

$$\therefore\ b_1=R\sin\mu \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$b_2=\tfrac{1}{4}\{\ \rho_{45}\sin 2\pi/4+\rho_{90}\sin 4\pi/4+\rho_{135}\sin 6\pi/4+\ \ldots\ +\rho_0\sin 16\pi/4\ \}$$

$$\therefore\ b_2=l/2\ [\cos\psi_{45}-\cos\psi_{135}] \quad . \quad . \quad . \quad . \quad (22)$$

$$b_3=\tfrac{1}{4}\{\ \rho_{45}\sin 3\pi/4+\rho_{90}\sin 6\pi/4+\rho_{135}\sin 9\pi/4+\ \ldots\ +\rho_0\sin 24\pi/4\ \}$$

$$\therefore\ b_3=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Making a summary of the results, obtained above, for the curve to pass exactly through eight equi-distant ordinates and writing $A_0=a_0/2$, $A_2=a_2$, $A_4=a_4/2$, $B_1=b_1$, $B_2=b_2$.

$$\therefore\ \rho=A_0+A_1\cos\theta+A_2\cos 2\theta+A_4\cos 4\theta+B_1\sin\theta+B_2\sin 2\theta \quad . \quad (24)$$

where

$$A_0=\tfrac{1}{4}\{\ r\ [1+\cos\phi_{90}+2\cos\phi_{45}]+l\ [\cos\psi_0+\cos\psi_{45}+\cos\psi_{90}+\cos\psi_{135}]\ \} \quad (25)$$

$$A_1=R\cos\mu \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

$$A_2=r/2\ \{\ 1-\cos\phi_{90}\ \}+l/2\ \{\ \cos\psi_0-\cos\psi_{90}\ \} \quad . \quad . \quad (27)$$

$$A_4=\tfrac{1}{4}\{\ r\ [1+\cos\phi_{90}-2\cos\phi_{45}]+l\ [\cos\psi_0-\cos\psi_{45}+\cos\psi_{90}-\cos\psi_{135}]\ \} \quad (28)$$

$$B_1=R\sin\mu \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

$$B_2=l/2\ [\cos\psi_{45}-\cos\psi_{135}] \quad . \quad . \quad . \quad . \quad . \quad (30)$$

Now assume that the angular velocity ω (or $d\theta/dt$) of the crank pin to be constant, then

$$d\rho/dt=\omega\ [-A_1\sin\theta-2A_2\sin 2\theta-4A_4\sin 4\theta+B_1\cos\theta+2B_2\cos 2\theta] \quad (31)$$

$$d^2\rho/dt^2=-\omega^2\ [A_1\cos\theta+4A_2\cos 2\theta+16A_4\cos 4\theta+B_1\sin\theta+4B_2\sin 2\theta] \quad (32)$$

If the displacement from the T.D.C. be denoted by Δ, then :—

$$\Delta=\rho_{max}-\rho$$

$$\therefore\ d\Delta/dt=-d\rho/dt \text{ and}$$

$$d^2\Delta/dt^2=\omega^2\ [A_1\cos\theta+4A_2\cos 2\theta+16A_4\cos 4\theta+B_1\sin\theta+4B_2\sin 2\theta] \quad (33)$$

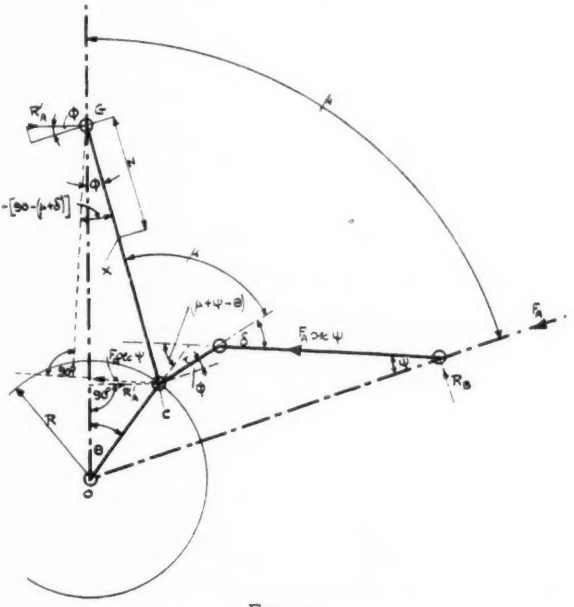

FIG. 2.

We will now consider the reactions and stresses due to a force F_A acting at the gudgeon pin of the piston operated by the auxiliary rod (see Fig. 2), this force being due to the gas forces and the forces due to the inertia of the reciprocating masses.

Then the force in the auxiliary rod $= F_A \sec \psi$ . . (34)

and reaction on the cylinder wall, $R_B = F_A \tan \psi$ . . (35)

Taking moments about the crank pin C, we have the reaction at the gudgeon pin of the piston in the " master " cylinder

$$R'_A = F_A \sec \psi r \sin \delta / L \cos \phi \quad . \quad . \quad . \quad . \quad (36)$$

Let R_C be the reaction at C due to the force F_A, then taking moments about G:—

$$\text{Moment of } R_C = F_A \sec \psi \, [L - r \sin \delta / \sin (\delta + \mu)] \cos \{ -[90 - (\delta + \mu)] \}$$
$$= F_A \sec \psi \, [L - r \sin \delta / \sin (\delta + \mu)] \sin (\delta + \mu)$$
$$= F_A \sec \psi L \sin (\delta + \mu) - (F_A \sec \psi r \sin \delta / L \cos \phi) \, L \cos \phi$$

Hence R_C may be divided into two forces, the first, $(F_A \sec \psi)$, parallel to the line of the auxiliary rod; and the second, (R'_A), parallel to the reaction at the gudgeon pin G, both acting in the same direction as the forces.

The force $F_A \sec \psi$ acting along the auxiliary rod gives rise to a bending moment at section X, distant z from G of magnitude:—

$$BM_x = F_A \sec \psi r \sin \delta z / L \quad . \quad . \quad . \quad . \quad (37)$$

when z is less than $[L - r \sin \delta / \sin (\mu + \delta)]$

$$\text{and } BM_x = F_A \sec \psi \, (L - z) \, [r \sin \delta / L - \sin (\delta + \mu)] \quad . \quad . \quad (38)$$

when z is greater than $[L - r \sin \delta / \sin (\mu + \delta)]$

The radial component of the forces at the big-end (see Figs. 1 and 2).

$$R_A = -F_A \sec \psi \cos (\mu + \psi - \theta) + R'_A \sin \theta$$
$$\therefore \; R_A = F_A \sec \psi \, [(r \sin \delta \sin \theta) / L \cos \phi - \cos (\mu + \psi - \theta)] \quad . \quad (39)$$

R_A is considered positive when it acts away from O.

The tangential component of the forces at the big-end (see Figs. 1 and 2).

$$T_A = F_A \sec \psi \, [(r \sin \delta \cos \theta) / L \cos \phi - \sin (\mu + \psi - \theta)] \quad . \quad . \quad (40)$$

T_A is considered positive when it tends to increase the angle θ.

Thrust in master rod at X, where z is less than $[L - r \sin \delta / \sin (\mu + \delta)]$.

$$P_A = R'_A \sin \phi = (F_A \sec \psi r \sin \delta \tan \phi) / L \quad . \quad . \quad . \quad (41)$$

Thrust at X, where z is greater than $[L - r \sin \delta / \sin (\mu + \delta)]$.

$$P_A = R'_A \sin \phi + F_A \sec \psi \cos (\mu + \delta)$$
$$P_A = F_A \sec \psi \, [(r \sin \delta \tan \phi) / L + \cos (\mu + \delta)] \quad . \quad . \quad (42)$$

P_A is considered positive when it produces compression in the master rod.

Angular Velocity and Acceleration of an Auxiliary Connecting Rod

Referring to Fig. 1.

$$\sin \psi = 1 / l \, [R \sin (\mu - \theta) + r \sin \phi]$$

Substituting for $\sin \phi$ from equation (2) and expanding.

$$\therefore \; \sin \psi = (R / l) \, [\sin \mu \cos \theta - \cos \mu \sin \theta + r \sin \theta / L]$$
$$\therefore \; \sin \psi = (R / l) \, [\sin \mu \cos \theta - \{ \cos \mu - r / L \} \sin \theta]$$

$$\text{Let } A = (R \sin \mu) / l \quad . \quad . \quad . \quad . \quad . \quad (43)$$

$$\text{and } B = (R / l) \{ \cos \mu - r / L \} \quad . \quad . \quad . \quad . \quad (44)$$

$$\therefore \; \sin \psi = A \cos \theta - B \sin \theta$$
$$\therefore \; (d / d\theta) \sin \psi = -A \sin \theta - B \cos \theta \text{ also } d \sin \psi / d\psi = \cos \psi$$
$$\therefore \; (d\psi / d\theta) = (-A \sin \theta - B \cos \theta) / \cos \psi$$
$$\therefore \; (d\psi / d\theta) = (-A \sin \theta - B \cos \theta) / \{ 1 - (A \cos \theta - B \sin \theta)^2 \}^{\frac{1}{2}} \quad (45)$$

$$d^2\psi/d\theta^2 = [\ \{\ 1-(A\cos\theta - B\sin\theta)^2\ \}^{\frac{1}{2}}\ \{\ -A\cos\theta + B\sin\theta\ \}$$
$$\div\ \{\ 1-(A\cos\theta - B\sin\theta)^2\ \}\ ] - [\ \{\ -A\sin\theta - B\cos\theta\ \}$$
$$\{\ \tfrac{1}{2} - 2\ (A\cos\theta - B\sin\theta)\ (-A\sin\theta - B\cos\theta)\ \}\ /\ \{\ 1-(A\cos\theta - B\sin\theta)^2\ \}^{3/2}]$$
$$\therefore\ d^2\psi/d\theta^2 = \{\ (-A\cos\theta + B\sin\theta)\ [(1 - A^2\cos^2\theta + 2AB\sin\theta\cos\theta - B\sin^2\theta)$$
$$-(A^2\sin^2\theta + 2AB\sin\theta\cos\theta + B^2\cos^2\theta)]\ \}\ /\ \{\ [1-(A\cos\theta - B\sin\theta)^2]^{3/2}\ \}$$
$$d^2\psi/d\theta^2 = (-A\cos\theta + B\sin\theta)\ (1 - A^2 - B^2)/\ \{\ 1-(A\cos\theta - B\sin\theta)^2\ \}^{3/2} \qquad (46)$$

Stress in Rod Due to Fling

Referring to the point Q, distant λ from the gudgeon pin (see Fig. 1), we can divide its acceleration into the following components:—

(1) An acceleration $(\lambda d^2\psi/dt^2)$ acting at right angles to the rod.

(2) An acceleration $(-\sin^2\psi d^2\Delta/dt^2)$ acting at right angles to the rod.

(3) An acceleration acting in the direction of the rod.

Hence the total acceleration of the point Q at right angles to the rod $= \lambda d^2\psi/dt^2 - \sin\psi d^2\Delta/dt^2$.

$$\therefore\ \text{Force at } Q = (W/g)\ (\lambda d^2\psi/dt^2 - \sin\psi d^2\Delta/dt^2) = (W\omega^2/g)(\lambda d^2\psi/d\theta^2 - \sin\psi d^2\Delta/dt^2)$$

where W = weight of the rod per unit length (constant).

These forces give rise to a "reaction" at the gudgeon pin at right angles to the auxiliary rod of magnitude R_M, where

$$R_M = (W\omega^2/gl)\ [ld^2\psi/d\theta^2 \cdot l/2)\ l/3 - (\sin\psi l \cdot d^2\Delta/d\theta^2)\ l/2]$$
$$\therefore\ R_M = (W\omega^2 l/2g)\ [d^2\psi/d\theta^2 \cdot l/3 - \sin\psi \cdot d^2\Delta/d\theta^2]$$

Let bending moment at $Q = M_\lambda$

$$\therefore\ M_\lambda = W\omega^2/g \cdot \lambda \cdot d^2\psi/d\theta^2 \cdot \lambda/2 \cdot \lambda/3 - W\omega^2/g \cdot d^2\Delta/d\theta^2 \cdot \sin\psi \cdot \lambda \cdot \lambda/2$$
$$- W\omega^2/2g\ (l)\ [l/3 \cdot d^2\psi/d\theta^2 - d^2\Delta/d\theta^2 \cdot \sin\psi]\ \lambda$$
$$\therefore\ M_\lambda = W\omega^2\lambda/g \cdot \{\ (\lambda^2 - l^2)/6 \cdot d^2\psi/d\theta^2 - (\lambda - l)/2 \cdot d^2\Delta/d\theta^2 \cdot \sin\psi\ \}$$
$$\therefore\ M_\lambda = W\omega^2\lambda/2g \cdot (\lambda - l)\ \{\ (\lambda + l)/3 \cdot d^2\psi/d\theta^2 - d^2\Delta/d\theta^2 \cdot \sin\psi\ \} \qquad (47)$$

Equation (47) gives the bending moment at Q, hence since we know the modulus of section (constant for the rod), we may determine the stresses at any point of the rod and for any crank angle.

The assumption that the section of the rod be uniform is justifiable since there are no direct bending forces acting on the rod and the stresses are practically constant along the rod.

APPENDIX I.

Evaluation of the Coefficients of a Fourier's Series for the Case of 60° V-Type Engine

Referring to Fig. 1, let $R = 2.375''$, $L = 8.3125''$, $r = 2.375''$, $\mu = 60°$, $L/R = 3\frac{1}{2}$. Then the distance from O to T.D.C. of the master cylinder is $10.6875''$, and making this distance the same for the "auxiliary" cylinder, we have from equation (4)

$$10.6875 = 2.375\ [\cos(\pi/3 - \theta) + \cos\phi] + l\cos\psi.$$

Now, for various values of θ we may determine the values of ϕ and if we approximate the value of l we obtain various values of the R.H.S. of the above equation. Plotting these values against θ we obtain the maximum value of the R.H.S. and so determine the difference between this maximum value and the required maximum (*i.e.*, $10.6875''$). We can now readjust our value of l and repeat the process until we arrive at the closest practical approximation. In the case considered the value of l was found to be $6.038''$ (to the nearest $1/1000''$)

and the maximum value of ρ occurs when the crank angle θ has the value $62^\circ\ 12'$. This value of l gives a value of $\rho_{max}=10.687645''$ an error of $0.000145''$.

We may calculate now the values of ϕ_{45}, ϕ_{90}, ψ_0, ψ_{45}, etc., from equations (2) and (3) and hence the values of A_0, A_1, etc., from equations (25) to (30).

This gives us the required approximation for ρ, *i.e.*,

$$\rho=8.173351+1.1875\cos\theta-.12031489\cos 2\theta-.00115429\cos 4\theta$$
$$+2.056810\sin\theta+.08948899\sin 2\theta.$$

By hypothesis this equation gives a curve which has exact values of ρ at crank angles 0, $\pi/4$, $\pi/2$, $3\pi/4$, etc. The departure from the true value between the angles 0 and $\pi/4$ is shown in Fig. 3. It will be noticed that the maximum error has the value $-(.001266'')$ giving an error of 0.02665 per cent. of the stroke.

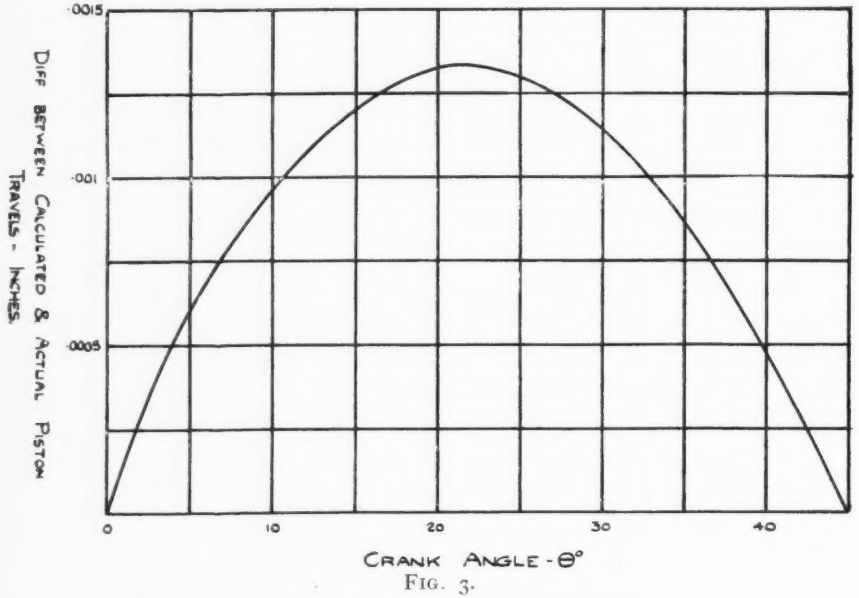

FIG. 3.

The above example shows the degree of accuracy of the method and justifies its use.

APPENDIX II.

A Method of Determining the "Out-of-Balance" Forces of an Engine with Articulated Rods

Let us consider the case of an 8-cylinder 90° V-type engine, with a crank of the form shown in Fig. 4, in which master rods operate the pistons in the cylinders 2, 4, 6, 8, and auxiliary rods operate the pistons in the cylinders 1, 3, 5, 7.

Referring to Fig. 1, let $R=2.375''$, $L=8.3125''$, $l=6.038''$, $L/R=3\frac{1}{2}$, $\mu=90^\circ$, then in order that ρ_{max} may have the same value as $(R+L)$, r must have the value of $2.400''$.

Now if m be the mass of the reciprocating parts (assumed to be the same

for all cylinders), and if ω be the constant angular velocity (*i.e.*, $d\theta/dt$) of the crank, then the inertia force developed may be written in the form

$$*f = mRw^2 (\cos\theta + p_2 \cos 2\theta + p_4 \cos 4\theta + \ldots)$$

or more generally :—

$$f = mR\omega^2 p_n \cos n\theta$$

where $p_n = n^2 q_n$, $N = L/R$ and

$$q_0 = N - 1/4N - 3/64N^3 - 5/256N^5 - 175/16384N^7, \text{ etc.}$$
$$q_2 = 1/4N + 1/16N^3 + 15/512N^5 + 5/4096N^7, \text{ etc.}$$
$$q_4 = -1/64N^3 - 3/256N^5 - 35/4096N^7.$$

Writing $mw^2 = \lambda$, then

$$f = \lambda R p_n \cos n\theta$$

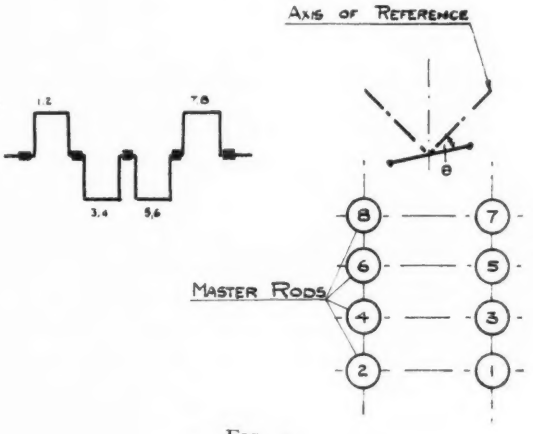

FIG. 4.

Now equation (33) may be written in the same form and hence the inertia force for a piston operated by an auxiliary connecting rod may be written in the form

$$f' = \lambda [C_n \cos n\theta + D_n \sin n\theta]$$

where $C_n = n^2 A_n$, $D_n = n^2 B_n$; A_n and B_n having the values obtained from equations (26) to (30).

Using the above expressions for f and f' we can write down equations giving the total forces for each cylinder. These forces we will consider as vectors and refer them all to one axis (see Fig. 4), in order that they may be summed algebraically.

For cylinders 1 and 7 $f'/2 = \lambda [C_n \cos n\theta + D_n \sin n\theta]$

,, 3 and 5 $f'/2 = \lambda [C_n \cos n(\theta+\pi) + D_n \sin n(\theta+\pi)]$

,, 2 and 8 $f/2 = \lambda R [p_n \cos n(\theta+\pi/2)]\ e^{-i\pi/2}$

,, 4 and 6 $f/2 = \lambda R [p_n \cos n(\theta+3\pi/2)]\ e^{-i\pi/2}$

where $i = \sqrt{-1}$.

Summing we have the total inertia force along the axis of reference :—

$$F_n/2 = \lambda \{ C_n [\cos n\theta + \cos n(\theta+\pi)] + D_n [\sin n\theta + \sin n(\theta+\pi)] - iRp_n [\cos n(\theta+\pi/2) + \cos n(\theta+3\pi/2)] \}$$

* See *A Treatise on Engine Balance Using Exponentials*, by P. Cormac (Chapman & Hall).

If $n=1$.

$$F_1/2=\lambda\ \{\ C_1\ [\cos\theta-\cos\theta]+D_1\ [\sin\theta-\sin\theta]-iR\ [\ -\sin\theta+\sin\theta]\ \}$$

$$\therefore\ F_1=0,\ \text{which is also the result if all rods were master rods.}$$

If $n=2$.

$$F_2/2=\lambda\ \{\ C_2\ [\cos 2\theta+\cos 2\theta]+D_2\ [\sin 2\theta+\sin 2\theta]-iRp_2\ [\ -\cos 2\theta-\cos 2\theta]\ \}$$

$$\therefore\ F_2=4\lambda\ \{\ [C_2\cos 2\theta+D_2\sin 2\theta]+i\ [Rp_2\cos 2\theta]\ \}$$

From the expressions for f and f' given above, it will be seen that if all the rods were master rods $C_2=Rp_2$ and $D_2=0$, hence for all master rods

$$_MF_2=4\lambda Rp_2\ [1+i]\cos 2\theta.$$

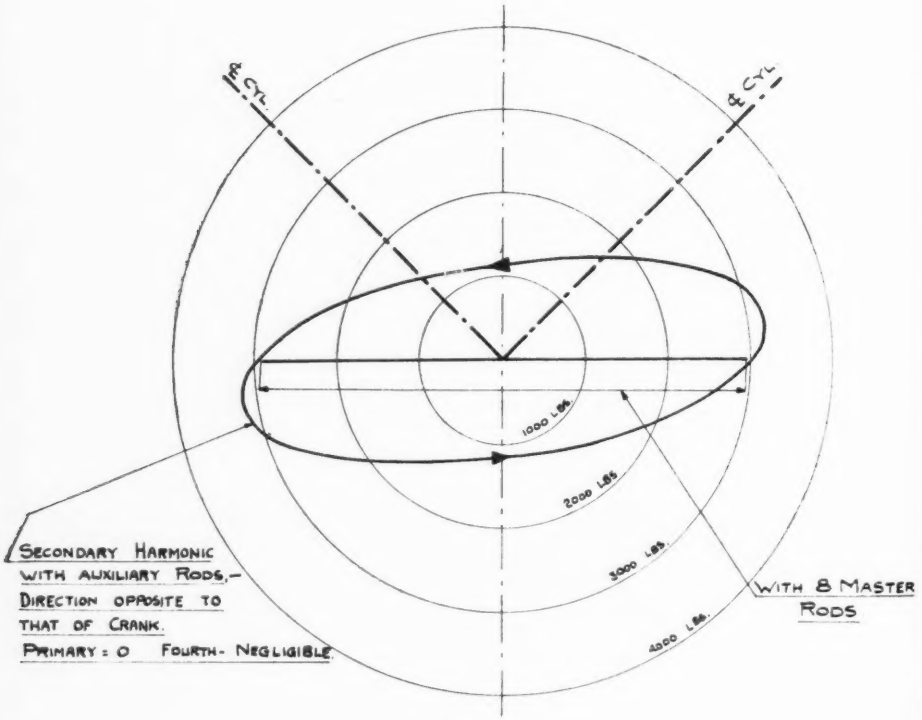

FIG. 5.

If $n=4$.

$$F_4/2=\lambda\ \{\ C_4\ [\cos 4\theta+\cos 4\theta]+D_4\ [\sin 4\theta+\sin 4\theta]-iRp_4\ [\cos 4\theta+\cos 4\theta]\ \}$$

$$\therefore\ F_4=4\lambda\ \{\ [C_4\cos 4\theta+D_4\sin 4\theta]-i\ [Rp_4\cos 4\theta]\ \}$$

For all master rods $C_4=Rp_4$ and $D_4=0$, hence

$$_MF_4=4\lambda Rp_4\ [1-i]\cos 4\theta.$$

Evaluating our required coefficients (which may be done with sufficient accuracy on a slide rule), we have

$$p_2=.2916,\ p_4=-(.0058),\ A_2=-(.1738),\ B_2=-(.1412).$$

If the crank makes 2500 r.p.m. then $w = 261.9$, and taking the reciprocating mass as $4\frac{1}{4}$ lbs. per cylinder, then $\lambda = 4\frac{1}{4}/12g \cdot (261.9)^2 = 753.5$. Hence substituting

$$_{M}F_2 = 4 \times 753.5 \times 2.375 \times .2916\,[1 + i] \cos 2\theta$$

$$\therefore\ _{M}F_2 = 2088\,[1 + i] \cos 2\theta.$$

This represents a horizontal force of maximum magnitude equal to $\pm(2088\sqrt{2}) = \pm 2950$ lbs.

Also $F_2 = 3013\,\{\,[4\,(.1738) \cos 2\theta + 4\,(.1412) \sin 2\theta] + i\,[2.375\,(.2916) \cos 2\theta]\,\}$

$$\therefore\ F_2 = [2097 \cos 2\theta + 1704 \sin 2\theta] + i\,[2088 \cos 2\theta].$$

Substituting various values of θ in this expression we obtain values of F_2 which are shown plotted on Fig. 5.

A.M. Communique No. 1401.

R.A.F. CAPE FLIGHT (OFFICIAL ACCOUNT)

(Abridged)

Organisation for the Flight

The flight of four aircraft of the Royal Air Force from Cairo to the Cape and back to England was purely a Service flight carried out in the ordinary course of Royal Air Force training and no attempt was made to break records. The whole flight was completed without incident, according to programme and without any change of engines.

The object of the flight was to visit the Dominion of South Africa and the various colonies en route; to gain experience in long distance flying in formation, keeping to a scheduled time-table, and so to test the regularity with which reinforcements can be despatched by air, to gain experience in flying through changing climates and conditions, and over new country, to co-operate with the local forces stationed in close proximity to the route followed, and last but not least to visit the South African Air Force.

The time of year during which the flight was to take place had been fixed and owed its fixture to the report of the Meteorological Department.

Quite briefly the flight was to start from Cairo on March 8th, 1926, and finish there on June 14th, 1926.

The Governments of the Soudan, Uganda, Kenya, Tanganyika, N. Rhodesia, S. Rhodesia, Bechuanaland and the Union of South Africa had been communicated with in regard to the provision of landing grounds, and as the flight passed over a strip of the Belgian Congo between Abercorn and N'Dola the permission of the Belgian Government had been sought and obtained.

The flight was to be composed of four aeroplanes. A spare aeroplane and spares were to be sent to Aboukir, a spare aeroplane, two spare engines and various spares were to be dumped at Kisumu (Lake Victoria). A spare aeroplane, four spare engines and appropriate spares were to be dumped at either Cape Town or Pretoria.

Thus the total number of aeroplanes and engines allotted for the flight were seven aeroplanes and 10 engines.

Petrol, oil and ground stores in the Northern Section were to be supplied by the Middle East Command, whilst the Asiatic Petroleum Company undertook to deliver the quantities necessary at all landing grounds south of Nimule.

About the middle of October, the type of aeroplane and engine were finally decided upon. They were to be Fairey IIID aircraft with Napier Lion Series V. engines.

On November 6th, 1925, the flight formed at Northolt, under the command of Wing Commander C. W. H. Pulford, O.B.E., A.F.C., though it was not complete with personnel till 1st December. This aerodrome was selected as the works of the Fairey Aviation Company were close to it.

Apart from carrying out consumption tests every opportunity was taken to fly the practice aeroplanes when heavily loaded, an area of 400 yards square being marked out for landing and getting off. Pilots were impressed with the way both in which the IIID got off and pulled up once the tail skid was on the ground.

The natural tendency when preparing lists of equipment is to try and take everything so as to be prepared for any eventuality. The Officer Commanding the flight held the belief that " If you carry a lot of spares you will want them; if you don't you won't feel their need." He determined, therefore, that the aeroplanes when fully loaded should not, if possible, exceed their ordinary service load. The weight of equipment which could be carried without exceeding this figure came to roughly 450 pounds, a very small weight when spare propellers and wheels, tools, arms, kits, medical stores, emergency rations and spare parts had to be included.

Wireless was not carried for the following reasons :—

(*a*) It was heavy.
(*b*) It would be of no value in Central Africa.
(*c*) It required a skilled operator to send and receive signals and to look after the set.

In order to save time when erecting at Aboukir the flight aeroplanes were packed with undercarriages on and centre sections in place. Special large cases were constructed for them.

As there was insufficient tunnel clearance on the Kenya and South African railways, the spare aeroplanes were packed in cases of normal size.

The intention had been to send four aeroplanes and most of the stores by a ship sailing on the 14th December; however, owing to the abnormal size of the aeroplane cases the ship could only take one. The remainder left for Alexandria on the 28th December.

Owing to information received from the Soudan to the effect that the landing grounds at Mongalla and Malakal would be unserviceable after the 3rd week in May owing to heavy rains, it was decided to start the flight on March 1st and finish on May 28th.

The aeroplanes of the flight were disembarked at Alexandria on the 25th January and, except for carrying away most of the overhead electric light cables and thus fusing all the lights in a street in Alexandria, were transported by road to Aboukir without incident. The first aeroplane was tested on the 29th January, the remainder at daily intervals.

Everything being in readiness the flight moved up to Heliopolis on the 25th of February and made ready to leave for the Cape at 07.00 hours on Monday, 1st March.

In addition to Wing Commander Pulford* the personnel engaged in the flight were :—

*Flight-Lieutenant P. H. Mackworth, D.F.C.
*Flight-Lieutenant E. J. L. Hope, A.F.C.
Flight-Lieutenant L. E. M. Gillman (Navigation).
Flying Officer A. A. Jones (Technical).
*Flying Officer W. L. Payne.
Sergeant Hartley (Fitter).
Sergeant Gardener (Rigger).

The pilots of the four machines are starred, the other flying personnel being earmarked for the special duties shown against their names.

The flight started from Heliopolis at 07.10 hours on March 1st and finished there at 08.35 hours on May 27th, one day ahead of time-table.

The total flying time for the four aeroplanes for the flight to the Cape and back to Cairo was approximately 568 hours. The actual time between Cairo and return for the leader's aeroplane was 140 hours 55 minutes, made up as follows: 68 hours 21 minutes in the outward flight; 72 hours 34 minutes in the return flight.

During the whole flight very little trouble was experienced, and beyond having to replace one magneto, two airscrews and all the oil tanks, no major repairs were necessary.

The flight kept to programme almost the whole way. The leader was however compelled to adjust the programme slightly at Kosti, on account of very low visibility due to the after effects of a sandstorm, but otherwise the time-table was kept to exactly until Cape Town was reached.

On the return flight, as Nairobi had to be visited and also because orders had been issued to fly home by sea, the original time-table was advanced a little in order to gain the necessary time.

So far as the actual flying was concerned, after the first two or three days and when everybody had shaken down into routine, no serious difficulty arose. Although most of the country flown over between Kosti and Pretoria was bad for a forced landing, the pilots had such faith in their engines and aeroplanes that the idea of a forced landing seldom if ever crossed their minds.

The reliability of the engines and aeroplanes was no doubt a great factor in determining whether the flight kept to time-table or not. But it was also very largely due to the efficient ground organisation prepared by the parties of Royal Air Force personnel that had been sent in advance.

The Outward Flight

First Stage. 1st—3rd March

Cairo-Assiut, 220 miles. Assiut-Aswan, 260 miles. Time taken 4 hours 57 minutes.

At 07.10 hours on the 1st March the flight took off in formation from Heliopolis for Assiut against a strong head wind.

The wind changed from south to north at Samalut, thus enabling Assiut to be reached in 2 hours 28 minutes.

After filling up the flight left for Aswan at 11.28 with the wind astern and landed at Aswan after a bumpy trip at 13.57.

Hitherto it had been cool in Egypt, but at Aswan all the crews felt that blast of hot air which strikes the face when landing in hot countries.

The country between Cairo and Assiut has no outstandng features. There is the usual strip of cultivation along the banks of the Nile. Except for the Fayum Oasis, where it is much deeper, this strip extends on the western bank for perhaps five miles in depth, until it reaches the desert. It is much narrower on the eastern bank. The division between cultivation and desert is very sharply defined, the contrast between the green and the yellow being most marked.

From Fayum southwards the belt of cultivation narrows until Luxor is reached, where it almost ceases.

After Assiut the desert on each side of the cultivation appears to be hilly and is much intersected by valleys. Between Quara and Luxor the country is very broken.

It may be of interest here to describe the routine on landing which was adhered to during the whole flight.

Immediately on landing and whilst taxying in, R.A.F. ensigns were hoisted; they were not kept flying in flight owing to the heavy wear and tear. Air intake plugs, airscrew, engine, cockpit and compass covers were immediately put on. The aeroplanes were then pegged down and flying controls secured. Where the ground was too hard for screw pickets heavy weights such as full oil or petrol drums were used instead. The usual practice was to peg down with one picket to each wing tip, one to the airscrew, and one to the tail, the camber gear being wound down to normal.

In localities where there was any likelihood of rain all petrol tank air vents were plugged in order to prevent water getting in.

Refuelling and routine inspections were then proceeded with.

On the 2nd March when work was completed the flight were shown round the Aswan Dam.

Second Stage. 3rd—4th March

Aswan-Wadi Halfa, 185 *miles. Wadi Halfa-Atbara,* 350 *miles. Time taken* 5 *hours* 46 *minutes.*

The flight left Aswan for Wadi Halfa at 07.09 steering by compass. Halfa was reached at 09.04. Aircraft were filled up to full stowage of petrol, taking eight gallons extra in the rear seat as the next journey was the first long flight.

Halfa was left for Atbara at 10.52 on a compass course for Abu Hamed.

Over the Nubian Desert up to 6,500 feet it was found to be very bumpy, and the flight struck particularly heavy bumps when passing over the numerous jebels (hills) between Halfa and Abu Hamed.

This part of the flight was very monotonous, as for two hundred miles there is nothing but sand and rocky jebels to be seen. The railway was sighted occasionally and the Nile was seen away on the starboard bow whilst still some distance from Abu Hamed.

After Abu Hamed it became more interesting as the course to Atbara lay over the Nile.

Atbara was reached at 14.43 after a flight of 3 hours 51 minutes.

The country between Aswan until close to Elder is not very hilly; in fact it is quite flat in some places, but round and for some distance beyond Elder the country is very broken up. The eastern bank of the Nile is a mass of sharply conical and jagged hills.

Third Stage. 4th—6th March

Atbara-Khartoum, 175 *miles. Time taken* 2 *hours* 27 *minutes.*

Atbara was left for Khartoum at 09.39 hours, but the flight had to return after 20 minutes owing to one aircraft (No. 1102) developing a leaky petrol sight glass. A resumption was made at 10.32 hours, the compass course lay to the eastward of the river and railway. Khartoum was reached at 12.38.

The blast of hot air on landing was, according to the leader's report, like an oven door being suddenly opened. It was learnt afterwards that it was 105° in the shade.

The desert between Atbara and Khartoum looks flat though it is cut up by innumerable wadis. After Shendi rugged and isolated jebels occur until quite close to Khartoum. Khartoum itself lies at the junction of the Blue and White Niles. Viewed from above the difference in colour between the Blue and White Nile is most marked.

The flight remained at Khartoum from the 4th to 6th March, the aeroplanes being housed in two Bessoneau hangars erected for the Detached Flight of No. 47 Squadron stationed at Khartoum.

Normal flight routine was carried out and small adjustments made where necessary.

An haboob (sandstorm) struck Khartoum from the north-west at sunset on the evening of the 5th March. It was the flight's first experience of such a thing and was found to be very unpleasant. Although the aeroplanes were housed, the precaution had been taken before leaving them of putting on all covers and inserting plugs in the air intakes, so that these were not filled with sand.

Fourth Stage. 6th—8th March

Khartoum to Kosti, 175 miles. Time taken 2 hours 25 minutes.

The flight left Khartoum for Kosti and Malakal at 07.25 on the 6th March, Mr. Cobham leaving for Wadi Halfa shortly before they took off.

The flight followed the Nile, as it was very thick owing to the haboob the night before. The visibility was under a mile in places. An endeavour was made to climb out of it, but at 7,000 feet it was no better and the Nile was lost to view.

At Kosti at 09.50 the flight landed, having increased the length of the journey by about 50 miles by following the river.

Judging from the crowd the whole village appeared to have turned out to see them land.

As the visibility appeared to have grown worse rather than better it was decided to stay the night at Kosti.

Kosti is easy to pick up from the air as the railway bridge over the Nile, some two miles south, makes a very good landmark; the locomotive sheds and sidings in Kosti are also very conspicuous.

The white population is about six all told, consisting of the District Commissioner and railway officials.

Having received a weather report from Malakal reporting moderate visibility the flight left Kosti at 09.27 on the 7th March, but after flying south for about 15 miles the visibility became worse than the day before; the flight, therefore, returned to Kosti.

Shortly after landing another weather report was received from Malakal stating the visibility was at that time low. It was decided, therefore, to wait another day.

Fifth Stage. 8th—10th March

Kosti-Malakal, distance 260 miles. Time 3 hours 53 minutes.

The visibility on the morning of the 8th appeared to be no better, but it was imperative to get on so as to keep to the time-table. The flight, therefore, left Kosti at 09.26. The Nile was followed the whole way until Malakal was reached at 13.19 hours.

As there was a following wind of about 10 m.p.h., the distance flown must have been approximately 320 miles.

It was too thick, accurately to report on country flown over; however, it could be seen that after passing Kosti Bridge there were scattered trees which appeared to get more dense to the southward. Round Renk the bush is very dense. The country from about 20 miles south of Kosti looked very rough though a forced landing might have been possible.

Malakal is the headquarters of the White Nile Province and lies on the eastern bank of the river, which there is about a quarter mile broad.

As a malarial district had now been reached, the flight started taking five grains of quinine daily. This was kept up until Pretoria.

Sixth Stage. 10th—12th March

Malakal-Mongalla, distance 350 miles. Time taken 3 hours 54 minutes.

The flight left Malakal for Mongalla at 07.36, the course taking them over Fagak, Kongor, Awoi and Bor and then the east bank of the Nile. Not much of the country could be seen as the visibility was bad. The pilots found the constant murkiness very tiring. They could see very little of the country, and sitting for nearly four hours with nothing to do beyond steering a compass course became very monotonous.

Generally speaking, from Malakal to Kongor there is flat grassy plain alternating with scattered bush. After Kongor the bush gets much thicker. Nothing much was seen of the Sudd country, though some of it was passed over north of Bor. From the air the Sudd looked a very unwholesome locality, papyrus reeds and marsh seemed to stretch for miles and miles.

The flight landed at Mongalla at 11.30.

Mongalla is the headquarters of the Mongalla Province. It consists of a few bungalows built on the eastern bank of the Nile, which about there is only some 70 yards broad. A motor road connects it with Nairobi.

It was very hot and muggy at Mongalla. The temperature did not fall much at night and little relief was gained.

Seventh Stage. 12th—13th March

Mongalla-Nimule, distance 124 miles. Time taken 1 hour 32 minutes.

Having been warned that Nimule was the last place in the world at which to stop, the Commanding Officer had intended to fly to Kisumu in one day. If he had done so he would have been a day ahead of programme.

Just before starting, however, the starboard magneto of No. 1103 was found to be defective. This caused a delay of about 3½ hours, while a spare one was fitted.

The flight left Mongalla eventually at 10.18 and shaped course for Nimule. It was still thick, the visibility being about 1-2 miles. The course to Nimule passed over Rejaf.

On this flight also it was too thick for detail of the country to be seen; only a general account, therefore, is possible. Scattered and thick bush alternating with much rocky outcrop in the neighbourhood of Rejaf exists practically the whole way to Nimule. The ground rises all the way.

On the western bank of the Nile, some forty miles from Nimule and until Nimule itself is reached, there is a ridge of razor-backed hills which appear to be about 3,000 feet high.

The flight landed at 11.60 hours.

By the time the flight had completed refuelling it was too late to start for Kisumu, as it would have been a race against daylight.

The crews slept in their hammocks for the first time. All hammocks were provided with mosquito netting which covered the hammock like a bag.

Eighth Stage. 13th—17th March

Nimule to Kisumu, distance 320 miles. Time taken 3 hours 43 minutes.

The flight left the ground for Kisumu at 08.40, the course taking them over Lira, Soroti and Mbale.

The visibility for 1½ hours after "take-off" was poor, but at 10.15 hours the pall which had enveloped them ever since they left Khartoum disappeared.

The contrast in visibility was extraordinary, for inside ten minutes a visibility of about one mile increased to that of about 50 miles.

It is an interesting fact that the visibility was bad for so great a distance (over 1,200 miles). The Governor of Malakal said that such conditions were most unusual and could give no explanation of the cause.

It seemed improbable that it was all due to sand because after Kosti there is no sand. The leader's assumption is that if it was sand then there must have been a series of terrific sandstorms in the desert between Atbara and Abu Hamed, the wind carrying the sand-laden air southwards.

(In this connection Mr. Cobham reported that he flew in a sandstorm from Khartoum to Abu Hamed on the 6th March).

Apart from one or two rainstorms, which were easily avoided, the flight was without incident. Kisumu was reached at 12.33, a large crowd being at the aerodrome to watch the landing.

The flight was met at Kisumu by Flight-Lieutenant Emmett, M.C., D.F.C. (the officer in charge of the Central Section), and the ground party of one N.C.O. and three men. They had erected the spare aeroplane and had also installed most of the stores in a Bessoneau, which had been erected on the edge of the aerodrome.

For a hundred or so miles south-east of Nimule the country consists of thick bush with much rocky outcrop and many khors. After that open grassy plain is reached until well past Lira. There is much swamp and patches of forest in the neighbourhood of Soroti; the forest then gives way to open grass plains with occasional patches of bush. This type of country persists until the foot of the Escarpment, which overshadows Kisumu on the north, is reached. Their course lay over the foothills of Mount Elgon, which are densely wooded. At the time they passed, the mountain itself was wrapped in clouds and nothing could be seen of it. Except for the first 80 miles a forced landing looked possible nearly everywhere.

The rainy season had started at Kisumu when the flight arrived. It rained in the afternoon at any time after 4 p.m., but never rained in the morning. The rain practically all fell during thunderstorms which generally worked up from the eastward, and then burst over Kisumu to the accompaniment of terrific claps of thunder and vivid flashes of forked lightning.

Whilst at Kisumu all the aeroplanes were thoroughly inspected, the 25-hour inspection being carried out on all engines. The spare aeroplane (No. 1107), which had been erected by the ground party, was tested, and both spare pilots were given as much flying as possible.

Ninth Stage. 17th—19th March

Kisumu-Mwanza, distance 240 *miles. Mwanza-Tabora, distance* 185 *miles. Time taken* 4 *hours* 38 *minutes.*

The flight took off in formation at 07.15, and shaped course for Mwanza via Speke Gulf. The visibility from now onwards was extreme, so that much more of the country was seen.

The course took them over varied conditions of country, marsh, thick bush, scattered bush, open grass plain and rocky outcrop. Generally speaking there is better flying country inland than there is close to the shores of the lake.

Mwanza was reached at 09.50, in the presence of a large crowd of natives kept in check by a company of King's African Rifles.

The ground was very soft, large pools of water having formed nearly all over it.

As soon as the rain stopped the flight prepared to leave the ground, only to find that two aeroplanes had become bogged right up to the axles.

It took about 50 Askaris of the African Rifles on each aeroplane to man-handle them out.

It was found that the best way to get out when bogged was, to stop the engine, dig the ground from before the wheels, raise the tail and lift up along the main spars of the wing together, at the same time pushing on the wheels. This naturally took time, but was the only way to set about it. It proved useless to try to get out by use of the engine.

The ground was left for Tabora eventually at 13.15; despite the bogginess the aeroplanes took off very well. They landed at Tabora at 15.18, the Governor of Tanganyika, Sir Donald Cameron, being there to meet them. There was an enormous crowd of natives lining the edges of the aerodrome.

On landing the leader received, from the Air Ministry, a cable directing him to land at Nairobi on the return journey, if considered possible. Advice was sent to the Officer Commanding Central Section to arrange all details at Nairobi.

Bush exists most of the way between Mwanza and Tabora, though there are many large grass areas to be found up to half way. After that the bush becomes very thick, and the aircraft passed over some extremely rocky hills.

A road connects Mwanza with Tabora. Tabora was easily seen from the air as it is on the railway, with large workshops alongside it. It is the headquarters of the 2nd Battalion of the King's African Rifles.

The troops could not get over the fact that the flight had come from Mwanza in 2¾ hours. It seemed incredible to them, for it was a good 14 days' march away.

There is a good deal of malaria at Tabora. It is hot, but not unpleasantly so. During the rains it is a great place for thunderstorms. The rains had nearly ceased when the flight was there, but every night there were generally two or three separate thunderstorms in progress simultaneously, a few miles apart.

Tenth Stage. 19th—21st March

Tabora-Abercorn, distance 300 miles. Time taken 3 hours 13 minutes.

The flight left Tabora for Abercorn at 08.25, visibility being extreme. The course was laid to cross the northern edge of Lake Rukwa over the Tanganyika escarpment to Kasanga on Lake Tanganyika and from there down the Lulu past the Kalamba Falls to Abercorn.

Thick forest exists practically all the day between Tabora and the Tanganyika escarpment; there are a few open patches, but these appeared to be marsh. A forced landing without damage would have been impossible. It was a desolate and dreary country to fly over. There were few native villages owing to the prevalence of sleeping sickness.

The escarpment, which rises sheer from the plain, can be seen from many miles away. The top of the escarpment, some 40 miles broad, is not quite so thickly covered in forest, and there are many open patches which appeared good enough to land on.

As Lake Tanganyika is approached the ground drops very quickly, and as it drops so it becomes more wooded.

The shores of the lake are steep, the vegetation being extremely thick. A landing might be effected on what appeared to be narrow sandy patches along the shores of the lake, anywhere else would be quite impossible.

Abercorn lies about 16 miles from the southern end of the lake and about 3,000 feet above it. It is easily located from the air, as there is a small lake about one mile east of the village. It is a tiny little place, and only about 10 English people live there, of which about half are planters. Being so high up it has a delightful climate and is quite healthy. It is, however, very cut off from the outer world, as it is about 20 days' journey through forest and swamps from N'Dola, also the lake steamers run very infrequently; added to this the telegraph line is generally down. It was down on both occasions when the flight landed there.

Before the flight left England a dual source of supply of petrol and oil to Abercorn had been arranged, one lot by rail and steamer from Dar Es Salaam via Ujiji and the Lake, the other by rail and porters from Pretoria via Livingstone. Both lots arrived in time, though the consignment from Livingstone only arrived two days before the aeroplanes and that only after tremendous exertions on the part of the porters.

Eleventh Stage. 21st—23rd March

Abercorn-N'Dola, distance 342 *miles. Time taken* 4 *hours* 11 *minutes.*

Abercorn was left for N'Dola at 09.54. In spite of the low density of the air (.78) no wind, and eight gallons of petrol extra in the back seat, the aeroplanes got off well. The course took them over the northern edge of Lake Bangweulu, from thence to N'Dola, crossing a strip of the Belgian Congo between Bangweulu and the Luapula river.

Except for the forbidding-looking marshes of Lake Bangweulu and the mangrove swamps of the Luapula river there is thick forest all the way from Abercorn to N'Dola. It is monotonous country to fly over.

When south-west of Lake Bangweulu the aircraft saw ahead what looked like a wall of very heavy rainstorms, which stretched right across the course. Course was altered to the northward to avoid some of these and by diving between the gaps of others the aircraft managed to avoid them. At close quarters the storms looked very forbidding, the rain appearing to fall in one solid sheet.

Owing to these many alterations of course to avoid the rain, the railway was struck some 15 miles south of N'Dola. The leader reports that after a moment of doubt as to whether a turn north or south should be made, the matter was finally settled by sighting a heavy column of smoke on the starboard hand, which on closer inspection proved to be the smoke from the aerodrome fires at N'Dola.

The flight landed at N'Dola at 14.05.

This was the only occasion during the land flight that there was any doubt as to position.

Whilst at N'Dola, near which are important copper mines, two or three important mineral prospectors expressed the view that as the whole future of Northern Rhodesia was wrapped up in mining and in order that the mining industry could go ahead, aeroplanes were absolutely necessary for transport and survey. At present much time is wasted owing to poor communications. During the rains the roads are impassable and it takes days, sometimes weeks, to get from place to place.

Twelfth Stage. 23rd—25th March

N'Dola-Broken Hill, distance 104 *miles. Time taken* 1 *hour* 21 *minutes.*

The flight took off in formation at 10.00 for Broken Hill, landing there at 11.21, the whole population turning out to see the landing.

Thick forest exists between N'Dola and Broken Hill. There were one or two open spaces, but these were the marshy valleys of small streams.

Broken Hill is a mining town and is easily picked up from the air.

Thirteenth Stage. 25th—29th March

Broken Hill-Livingstone, distance 303 *miles. Time taken* 3 *hours* 21 *minutes.*

The flight left Broken Hill for Livingstone at 08.46, the course taking the aeroplanes over the Kafue River, Mazabuka, Batoka and the Kalomo River. A good deal of cloud was encountered, which necessitated flying at about 9,000 feet above sea level most of the time. The visibility was extreme. The spray from the Victoria Falls at Livingstone was sighted over 40 miles away.

Livingstone was reached at 12.07, the aeroplanes having first flown over the falls. The Governor and Lady Stanley were there to meet them.

The country between Broken Hill and Livingstone is mostly thick bush, but there are many more open spaces and also a good deal of marshy ground near the rivers. Near Madabuka there are several farms along the railways.

Fourteenth Stage. 29th—31st March

Livingstone-Buluwayo, distance 243 miles. Time taken 3 hours 6 minutes.

The flight took off from Livingstone at 10.08, and after saluting the Governor, shaped course for Buluwayo. The course took the aircraft over Wankie, Malindi, Gwaii, Nyamdlhovu, and then along the railway to Buluwayo.

Bumps were encountered partly due to the nature of the ground and partly to clouds.

The landing was made at 13.14.

Fifteenth Stage. 31st March—2nd April

Buluwayo-Palapwe Road, distance 200 miles. Time taken 2 hours 31 minutes.

When Mr. (Sir Alan) Cobham was met at Khartoum he reported that he had had difficulty in getting off at Buluwayo and had had to lighten his aeroplane before he could do so. (Buluwayo is 1,500 feet lower than Abercorn).

The flight, however, experienced no such difficulty.

The flight took off in formation at 10.09, and after saluting the Governor, shaped course for Palapwe Road. The course lay past the Matoppos to Francis Town where course was altered for Palapwe. After passing Francis Town course had to be altered to avoid a chain of rainstorms. Palapwe was reached at 12.40, the whole white population and many natives being there to see the landing. The Commanding Officer was introduced by the Resident Magistrate of Serowe to Tshkedi Khama the Regent of Bechuanaland.

There was little of interest about the country. The Matoppos district appeared very broken up, being a mass of rocks and kopjes; later the country became more open. Between Francis Town and the Matoppos there is a perfect speciment of a watershed, many streams rising there and flowing SSE towards the Limpopo River.

Between Francis Town and Palapwe much bush was seen, though from the air it did not look nearly so dense as the forest over which the aeroplanes had been flying for nearly 1,500 miles.

Palapwe Road is a small trading station. The population consists of about 20 Europeans, most of whom are engaged in trading with the natives and a large volume of trade is done.

Tshkedi Khama asked if the flight could fly over Serowe, which is the capital of Bechuanaland, whilst the flight was at Palapwe. This was done on the following day.

No. 1105 had to return and land owing to oil trouble, but the remainder after escorting her back continued the flight over thick bush country to Serowe.

Serowe is some 30 miles north-west of Palapwe, and is really quite a large native town with about 20,000 inhabitants.

The flight did not stop long over Serowe for the noise of the engines had stampeded all the cattle and donkeys in the place. These could be seen charging up and down the roads at full speed.

On landing at Palapwe the natives could not believe that the aeroplanes had been to Serowe and back in an hour as it would take them two days.

Sixteenth Stage. 2nd—5th April

Palapwe Road-Pretoria, distance 232 miles. Time taken 2 hours 43 minutes.

The flight took off in formation and left Palapwe Road for Pretoria at 07.31 hours. It was a cold morning with clouds at about 1,500 feet. After crossing the Limpopo River the tops of a range of hills which had to be crossed, were observed to be covered in clouds. To get over the aeroplanes were compelled to come down low, about 50 feet from the ground, and dodge about considerably.

Between Palapwe and the Limpopo River there is the bush veld. After the Limpopo until clear of the hills it is wooded and the ground is broken up. Once clear of the hills the open veld starts and it is fine flying country.

On landing the flight was met by General Brink (Chief of the General Staff), Colonel Sir Pierre van Ryneveld and the Mayor of Pretoria.

The aeroplanes were then wheeled into hangars and after lunch work was started on giving all machines the 25-hours' routine overhaul. Beyond one or two minor adjustments everything was found to be in perfect order. The wood shrinkage was considerable, and it was found necessary to tighten up all spar bolts.

Flight-Lieutenant W. E. Reason was in charge of the ground organisation on the Southern Section.

Seventeenth Stage. 5th—8th April

Pretoria-Johannesburg, distance 35 *miles. Time taken* 1 *hour* 1 *minute.*

The flight left Pretoria at 09.25 in company with 14 aeroplanes of the South African Air Force for Johannesburg. The whole formation was 19 strong as the spare machine was taken as well. The British flight was in the van, the South African flights being disposed astern.

Before landing at Johannesburg at 10.26 hours the formation flew the whole length of the reef which runs for about 20 miles east and west of Johannesburg. As soon as the flight landed at Johannesburg the South African aeroplanes returned to Pretoria.

Eighteenth Stage. 8th—11th April

Johannesburg-Bloemfontein, distance 227 *miles. Time taken* 2 *hours* 42 *minutes.*

The flight left Johannesburg for Bloemfontein at 02.33 hours on the 8th April. Although the density of air at Johannesburg gave a true height of about 8,000 feet no difficulty was found in taking off in formation. The course took the aeroplanes past Vereeniging, West Leigh, Kronstad and Virginia. The country flown over was all good and a forced landing could have been made anywhere. It is practically all rolling grass land with isolated kopjes here and there. Bloemfontein was reached at 12.15 hours in the presence of a large crowd.

On landing at Bloemfontein No. 1102 reported a leaky oil tank. Oil had luckily only started running out about half an hour before the landing.

On examination it was found that the port side of the tank was badly split. Repairs were made at once, but in the meantime a wire was sent to Pretoria to despatch a spare tank. This was received on the 9th and installed straight away.

A good deal of rain was encountered during the stay, which made conditions for working rather disagreeable.

Nineteenth Stage. 11th—12th April

Bloemfontein-Beaufort West, distance 304 *miles. Time taken* 3 *hours* 37 *minutes.*

The flight took off from Bloemfontein in formation and left for Beaufort West at 09.41 hours. The visibility was extreme, wind about 10 m.p.h. from the east.

The compass course lay over Jagersfontein and the Orange River, past Philipstown and Daar Junction, over Table Mountain direct to Beaufort West.

The flight took up close formation over Jagersfontein, as a request to fly over the town had been received.

There is a diamond mine to the south-west of the town which looks, from the air, like an enormous hole in the ground. The flight reached Beaufort West at 13.18 hours without incident.

As far as Jagersfontein the country is flat and open with flat-topped kopjes here and there.

After Jagersfontein the country becomes more broken up and the kopjes more numerous. In the vicinity of the Orange River the country from the air appears very broken up. The country to the west of Beaufort West and the railway is mountainous.

Twentieth Stage. 12th—19th April

Beaufort West-Cape Town, distance 266 miles. Time taken 3 hours 41 minutes.

The flight took off in formation for Cape Town at 09.26 hours, their course taking the aeroplanes along the railway, over Maljesfontein, over the Hex River Mountains, past Worcester and over the Drakensberg Mountains.

The visibility was extreme, the air being wonderfully clear. The Karoo Desert looked like the bed of an ancient sea, baked brown by the sun.

After Maljesfontein the country begins to rise and becomes very mountainous, especially to the south of the railway.

The Hex River Mountains took a peculiar formation from the air. They seemed to be comprised of gravel in distinct layers, outcrops of rock occurring at intervals, also a succession of spurs with circular backs and straight faces. The valleys all appeared to run north and south.

During the flight the aeroplanes had to climb to 11,000 feet above sea-level to clear the tops of the Drakensberg. After passing Worcester the Drakensberg Mountains were crossed and the flight were taken over the Cape Town plain until Cape Town was reached.

As they were crossing the Drakensberg the leader noticed No. 1102 climbing vigorously till finally lost above him at about 16,000 feet. As the pilot had implored him that morning not to fly too high on account of the cold he imagined he must have some very good reason for doing so. On taking up close formation some ten miles north of Wynberg there was still no sign of No. 1102; but as the flight passed Wynberg aerodrome No. 1105 signalled to the leader that No. 1102 had landed. The leader continued to fly over Cape Town and then returned to Wynberg and landed at 13.07 hours.

The flight was met by the Minister of Defence, the Chief of the General Staff and the Mayors of Wynberg and Cape Town.

No. 1102 reported that when over the Drakensberg Mountains her oil tank had again split. The pilot had climbed high so as to be able to have more time to select a landing ground should the engine seize. On finding the oil pressure holding he had opened his throttle and dived for Wynberg at full speed, arriving some 20 minutes before the remainder of the flight. It was disquieting to find a brand new tank splitting after only six hours' flying; it was decided, therefore, to get a new one made without delay locally. Further examination revealed the oil tank of No. 1103 to be cracked.

In these circumstances Messrs. Gearing, Ltd., of Cape Town, made four new 20-gauge copper tanks from the design that was supplied and these were installed. They stood up to their work very well and were still in the aeroplanes when the flight arrived in England.

The greatest assistance was received from the Headquarters of the Cape Garrison, a guard being provided at the aerodrome, and all cables and telegrams in connection with the flight being dealt with by them.

It rained heavily all day for two days and the weather was much colder than anything that had yet been experienced.

The Return Journey

Twenty-first Stage. 19th—20th April

Cape Town-Victoria West, distance 333 *miles. Time taken* 3 *hours* 6 *minutes.*

The flight took off in formation from Wynberg at 09.50 hours. After saluting His Excellency the Governor-General, who was present to see the departure, course was shaped for Victoria West.

Victoria West lies on the edge of the Karoo Desert. It is easily distinguished from the air as a kopje, beneath which it lies, had Victoria West marked on it in large white letters visible some 10 miles away.

Twenty-Second Stage. 20th—22nd April

Victoria West-Kimberley, distance 207 *miles. Time taken* 2 *hours* 38 *minutes.*

Owing to the sand the departure was made by aeroplanes singly at 10.35 hours, and after flying in close formation over the aerodrome they left for Kimberley. The course took them over the Orange River near Hope Town and then parallel to the railway to Kimberley. The weather was superb with extreme visibility. There was little to note in the country flown over, all of which was good flying country and a landing could be made practically anywhere. Kimberley was reached at 13.11 hours.

Twenty-third Stage. 22nd April—3rd May

Kimberley-Pretoria, distance 294 *miles. Time taken* 3 *hours* 28 *minutes.*

The flight took off in formation at 10.30 hours and shaped a course for Pretoria. The course lay over Boshof, Hoopstad, Potchefstroom and Johannesburg.

The flight was uneventful, though being the middle of the day bumps were encountered.

Between Kimberley and Pretoria the country is nearly all good for forced landing.

Pretoria was reached at 14.04 hours.

During the stay in Pretoria opportunity was taken thoroughly to overhaul the aeroplanes, controls being renewed where necessary. The engines were given the routine 25 hours overhaul, and all aeroplanes were swung for deviation.

As the return flight included Nairobi a new time table was prepared.

The return flight is only briefly described since most of the country was the same as that already passed over.

Twenty-fourth Stage. 3rd—5th May

Pretoria to Bulawayo via Palapwe Road.

Twenty-fifth Stage. 5th—6th May

Bulawayo-Livingstone.

Twenty-sixth Stage. 6th—7th May

Livingstone-N'Dola via Broken Hill.

Twenty-seventh Stage. 7th—9th May

N'Dola-Abercorn.

Twenty-eighth Stage. 9th—11th May

Abercorn-Tabora.

Twenty-ninth Stage. 11th—12th May

Tabora-Kisumu.

The flight left Pretoria early in the morning of the 3rd May. Buluwayo was reached without incident the same day after refuelling at Palapwe Road. A stay was made at Buluwayo till the 5th. Livingstone was reached on the 5th; N'Dola via Broken Hill on the 6th; Abercorn on the 7th; Tabora on the 9th and Kisumu on the 11th.

Between Kisumu and Tabora the flight, when in a mountainous area 80 miles south of Kisumu, ran into a series of blinding rain storms which stretched as far as Kisumu. When not in rain, low clouds were met with which were down to the ground in places. This low visibility resulted in collisions with the sides of hills and the tops of trees being narrowly averted. On arrival at Kisumu it was found that the fabric on the airscrews of Nos. 1102, 1104 and 1105 had in places started to strip.

Thirtieth Stage. 12th—15th May

Kisumu-Nairobi, distance 178 miles. Time taken 2 hours 7 minutes.

On the 12th the flight flew to Nairobi, the course being via Mau Summit (10,500 feet above sea-level) past Nakuru and over Lake Naivasha. Nairobi was reached after a flight of 2 hours 7 minutes. An enormous crowd had assembled to see the landing as no aeroplanes had been seen there before.

After leaving the marshy plain, east of Kisumu, the ground rose very rapidly until the top of the escarpment at Mau was reached; the ground then fell fairly rapidly until Lake Nakuru, where it appeared to be level as far as Lake Naivasha. This part of the country is bounded both on the east and the west by mountainous country. After Lake Naivasha another small escarpment had to be crossed before Nairobi was reached.

The country between Nakuru and Naivasha appeared to be a fine farming district.

It rained most of the time whilst at Nairobi, the aerodrome becoming very wet.

Thirty-first Stage. 15th—18th May

Nairobi-Kisumu.

Nairobi was left on the morning of the 15th at 10.27 hours. The ground was waterlogged and columns of spray rose as each aeroplane took off. As the clouds were low everywhere, course was shaped west, south of the N'Gong Hills over the Migungani Plain, and then north to Kisumu up to Kerocho Valley.

Heavy bumps were encountered as the aeroplanes were compelled to fly low on account of clouds. Numerous heads of buck and zebra on the Mingungani Plain were seen. At one point a head of giraffe was also seen galloping away. Kisumu was reached without incident at 12.49 hours.

On arrival at Kisumu a snake which had crept in and twined itself round the spokes of the leader's port wheel, whilst at Nairobi, was still there.

The 25-hour engine routine overhaul was carried out on all aeroplanes between the 15th and 16th May.

During the night of the 17th-18th May it rained heavily from 11 p.m. till 5 a.m.

Thirty-second Stage. 18th—19th May

Kisumu-Jinja, distance 116 miles. Time taken 1 hour 24 minutes.

A start was made for Mongalla via Jinja at 06.36 hours, but at 07.20 hours the flight was compelled to turn back owing to heavy rainstorms completely

barring the path. A fresh start was made at 14.18 hours on the same day, Jinja being reached at 15.42 hours. The weather just beyond Jinja appeared extremely black and threatening. The storm the night before had brought down the wires between Kisumu and Jinja. All telegrams for Uganda from Kenya (87 all told) were, therefore, taken by the flight.

Jinja is a small town. It possesses a wharf and jetty to which steamers can secure. The Nile rises at Jinja, the Rippon Falls being near by.

Thirty-third Stage. 19th—20th May

Jinja-Mongalla, distance 346 miles.

Jinja was left on the morning of the 19th, course being shaped for Mongalla. Very little of the intervening country was seen, owing to a ground mist which extended to within 30 miles of Nimule.

Mongalla was reached without incident after a flight of 4 hours 12 minutes. There had been rain two days previously and the landing ground was very soft in certain places. No. 1104 became bogged while taxying in and again when taking off the next morning. The other aeroplanes were fortunate not to get bogged also as the tracks of No. 1104 were only three feet to the left of the track followed by the remainder.

Thirty-fourth Stage. 20th—21st May

Mongalla-Malakal.

Thirty-fifth Stage. 21st—23rd May

Malakal-Khartoum.

Thirty-sixth Stage. 23rd—25th May

Khartoum-Atbara.

Thirty-seventh Stage. 25th—26th May

Atbara-Halfa.

Malakal was reached on the 20th and Khartoum on the 21st. It was very hot at Khartoum, the temperature being 115° in the shade.

Khartoum was left on the 23rd, Atbara being reached without incident. That evening a heavy sandstorm struck Atbara at sunset. The visibility next day was consequently very low. On the 25th, though the visibility was still very low, the flight left for Halfa. At Abu Hamed the visibility improved. Halfa was reached without incident after a flight of 4 hours 22 minutes.

Thirty-eighth Stage. 26th—27th May

Halfa-Assiut.

Halfa was left next morning as the sun rose, Aswan being reached without incident in 2 hours 34 minutes. The flight left Aswan again at 09.26 hours for Assiut, but had to return after 25 minutes' flying owing to the oil pressure in No. 1104 failing. No. 1105 reported similar trouble. The airscrew of No. 1102 was changed as the pilot reported excessive vibration. Some of the difficulties arising when flying over Africa are illustrated in the following paragraph from the leader's report:—

"On landing a second time there was nobody at the aerodrome and we could not open the petrol store. As there was a strong head wind it was essential to put in the amount of petrol used up on the abortive flight. After having waited for nearly three hours for someone to arrive I gave orders for the door to be broken down. This could not be done and we only succeeded in breaking the

lock. Finally, in desperation, I bought 32 gallons of M.T. spirit in the Aswan bazaar and had that put into the tanks. Aswan was finally left at 13.58 hours, Assiut being reached at 16.58 hours. It was very hot when we took off, the water rising to 96° and the oil to 74° before reaching cooler air at 5,000 feet. Over Sohag it looked as if another sandstorm was coming on and although we were at 7,000 feet it was extremely bumpy. No. 1105 was thrown about to such an extent that a flying wire parted. Later we found that we had passed over a small sandstorm. All aeroplanes nearly crashed on landing at Assiut owing to striking ridges which were not marked and could not be seen from the air."

Final Stage. 27th—29th May

Assiut-Heliopolis.

Assiut was left at 06.05 hours, Heliopolis being reached at 08.35 hours. When near Helwan an escort from Heliopolis joined the flight and took station on either quarter.

The Flight Home

The route selected was as follows:—Aboukir, Sollum, Suda Bay (Crete), Phaleron Bay (Athens), Corfu, Brindisi, Naples, Orbetello, Berre (near Marseilles), Crete, Hourtin (near Bordeaux), Brest, Lee-on-Solent.

The land flight having finished at Cairo on the 27th May, the Cape flight flew to Aboukir on the 29th May, and there work was at once started on overhauling the aeroplanes.

Each aeroplane was thoroughly overhauled and cleaned, the fabric being given a fresh coat of dope.

The engines were then given the usual 25-hour routine overhaul.

New airscrews suitably sheathed for float-plane work were also fitted.

Everything being in readiness by noon on the 8th June, the start of the flight was fixed for 10.15 hours on the 9th.

Although the flight home was perhaps not so interesting as that to the Cape and back, yet a number of places of great historical interest were passed. Further, it was the first time this route had been taken by float-planes.

Aboukir was left on the 9th June at 10.15 hours and the flight arrived, according to programme, at Lee-on-Solent on the 21st June at 13.02 hours, the total flying time taken by the four aeroplanes over this part of the route being approximately 164 hours. The actual time for the leader's aeroplane was 40 hours 30 minutes.

Except for an airscrew changed on one aeroplane at Berre, no major repairs were necessary.

The programme was adhered to with one exception, but this was only made possible by the efficiency of the ground organisation prepared in advance, together with the help which was received at every place. The Greek, Italian and French authorities were particularly helpful.

The flight experienced good weather until they reached Berre. At Berre a mistral commenced to blow the night before they left. In the morning it was blowing nearly a full gale from the N.N.W. Berre is situated in a lake; this enabled the aeroplanes to take-off, but as the wind was dead ahead and continued without abating the whole day, a stay was made at Crete. Next day, though still blowing hard, a start was made for Hourten.

At Toulouse the wind dropped and fog was encountered. The flight was therefore forced to fly at about 100 feet down the Garonne to Bordeaux where the fog lifted. Between Brest and Lee-on-Solent fog was again met with, necessitating the Channel being crossed at about 50 feet until the Needles were sighted.

Except for the flight from Brest to Lee, head winds were encountered all the way home.

When crossing the mountains of Calabria, between Brindisi and Naples, a curious phenomenon was experienced. At a point about six miles east of the main ridge the leader's aeroplane, for no apparent reason, lost height rapidly. Although the engine revolutions were 1,760 when the aeroplane commenced to lose height at 8,000 feet, it only stopped sinking at 6,800 feet when the revolutions were increased to 1,950. It is assumed that the aeroplane must have struck a down current of air (a head wind was blowing) as after about ten minutes it started to climb again with revolutions reduced to 1,800. The bumps over Calabria proved bad.

Conclusion

The Cape flight extended from March 1st till June 21st. The engine times for the four aeroplanes were as follows:—

No. 1102	...	...	...	186	hours	48	minutes.
No. 1103	...	...	...	190	,,	07	,,
No. 1104	...	...	...	184	,,	22	,,
No. 1105	...	...	...	183	,,	24	,,

The total distance flown by each aircraft was approximately 14,000 miles.

Throughout the flight officers and airmen received a most hearty welcome at all places of call and hospitality was lavished upon them.

The flight has been of great value to the Royal Air Force, as it has provided experience in long distance flying over new country and through changing climates. It should clearly prove to the world in general the reliability and the efficiency of British aircraft and engines, and the high state of efficiency of the Royal Air Force, the objects of the flight having been completely achieved.

RÉSUMÉ OF COMMERCIAL AND TECHNICAL INFORMATION

OCTOBER-NOVEMBER, 1926

Scientific and Technical Information abstracted from the Technical Press by the Directorates of Technical Development and Scientific Research (R.T.P.), Adastral House, Kingsway, London, W.C.2.

AIRCRAFT

Germany

New Twin-Engined Heinkel Aeroplane for Air Survey.

Luftfahrt, October 28th, 1926, No. 20. (11026)

The Heinkel Works have constructed a new type of twin-engined aeroplane specially designed for air survey.

The New Heinkel H.D.39 Newspaper-Carrier.

Illustrierte Flug-Woche, April 15th, 1926, No. 8. (21026)

The Heinkel H.D.39 was specially designed for the transport of newspapers and is evolved from the H.D.27 mail machine.

Hold and Arrangements for dropping newspapers.—The parcels to be carried and dropped are suspended in the hold near the c.g. of the aeroplane. Ten parcels of a maximum weight of 50 kg. each can be carried. The rack consists of three bearers and there are four parcels on either side and two in the centre. Even when the rack is full an attendant can enter the hold, access to which is by a sliding door provided in the floor and easily opened and closed from the pilot's cockpit.

The three bearers are connected by a system of transverse tubular members which facilitate the loading of the rack. The parcels are raised through a trap door in the floor of the fuselage by being wound on these transverse tubes by means of a system of hooks, pulleys and cords, and are thus led to their various points of attachment ready to be hooked on. The suspension and releasing device consists of a system of longitudinal tubes which are provided with small slots and on which the various release hooks hang during loading. The parcels are discharged by means of a lever operated by hand from the pilot's cockpit. The operation of this lever moves the tubes bearing the hooks in a longitudinal direction, so that the various slots come successively under the suspension hooks. The hooks slip through the slots and release the parcel.

The arrangement is such that only one parcel can fall at a time.

It is possible by adjustment of a certain device to drop any parcel as desired. It is noteworthy that the pilot is able to operate the release device himself should no special assistant be carried, the desired bearer being actuated. If an assistant is available, it is possible to change the places of the parcels during flight.

Undercarriage.—The undercarriage differs considerably from the standard type. It has no through axle, as this would interfere with the dropping of the newspapers, and consists of two entirely separate parts. The track is wide in order to ensure safe landing on rough ground. The wheels are carried by two faired-off struts which are articulated on the bottom longeron of the fuselage. The springing is by means of a third, divided strut which is articulated on the top longeron of the fuselage, and is provided with rubber cord shock absorbers enclosed in a streamlined casing towards the top of the strut.

Characteristics :—

Engine, 230 h.p. BMW IV.
Span, 14.8 metres (48ft. 6in.).
Height, 3.7 metres (12ft. 2in.).
Length, 10 metres (32ft. 10in.).
Wing area, 51 sq. m. (550 sq. ft.).
Power loading, 8.8 kg. h.p. (194 lbs./h.p.).
Wing loading, 39 kg./sq. m. (8 lbs./sq. ft.).
Weight empty, 1,250 kg. (2,756 lbs.).
Crew (two men), 170 kg. (375 lbs.).
Fuel, 230 kg. (507 lbs.).
Pay load, 400 kg. (882 lbs.).
Total useful load, 800 kg. (1,764 lbs.).
Total loaded weight, 2,050 kg. (4,520 lbs.).
Speed, 160-170 km./hr. (99-105 m.p.h.).
Landing speed, 72 km./hr. (45 m.p.h.).
Climb to 1,000 metres (3,280ft.), 7 min.
Range, 800 km. (500 miles).

France

Tests of a Bleriot-Spad, Type 61, in Poland.

Les Ailes, October 21st, 1926, No. 279. (31026)

The Polish Air Service has just carried out some interesting tests with a Bleriot-Spad, type 61, fitted with a 500 h.p. Hispano-Suiza engine.

The flights were carried out on the Mokotov Aerodrome by Widavski on September 15th, 1926.

The aeroplane, which carried a load of 399 kg. (879 lbs.), had a total loaded weight of 1,608 kg. (3,544 lbs.). Its wing area being 29.3 sq. m. (318.7 sq. ft.), the wing loading was 52.5 kg./sq. m. (10.74 lbs./sq. ft.). It climbed to 6,500 metres (21,320ft.) in 15 min. 37 sec., which indicates a theoretical ceiling of 9,050 metres (29,690ft.) and a service ceiling of 8,700 metres (27,540ft.).

With the engine developing 2,000 r.p.m. near the ground the speed is 253 km./hr. (157 m.p.h.); with 1,990 r.p.m. at 6,000 metres (19,680ft.) it is 236 km./hr. (146 m.p.h.).

The rate of climb which is 15.6 metres/sec. (51ft./sec.) near the ground, is 4.24 metres/sec. (13.9ft./sec.) at 6,000 metres.

The Ratier airscrew develops as high a speed as 1,798 r.p.m. at this altitude.

These fine performances put up by a French machine abroad under the control and direction of the Polish Technical Department reflect the greatest credit on French aircraft constructors.

This aeroplane is one of a series of Spad-Lorraine machines ordered from the Bleriot Works at Suresnes, the only modification that was made being a change of engine.

Tests and Flights of the Week

Liore et Olivier.

L'Aero-Sports, October 23rd, 1926, No. 542. (41026)

A new twin-engine Le O.12 three-seater bomber fitted with two 420 h.p. Gnome-Jupiter engines is being assembled. Lamothe is shortly going to deliver it to Serbia.

Schneider.

L'Aero-Sports, October 23rd, 1926, No. 542. (51026)

The Avi-Meta Department of the Schneider Works has just brought a large metal seaplane which is said to compare favourably with the best metal German

aircraft. It was designed by Lepage and is to be tested as a land aeroplane in the first instance by Moutonnier at Villacoublay.

Italy

The C.F.2 Sports Monoplane.

L'Aviazione, October 8th, 1926. (61026)

This low-wing monoplane is one of the two C.F.2 aircraft entered for the Italian Cup Race.

The cantilever wing is characterised by its high aspect ratio. The wing structure consists of two principal spars and thirteen ribs on each side of the fuselage.

The wings have their maximum thickness and chord at the root section and taper gradually in thickness and in chord towards the tips, which are semi-circular. The two ailerons, which also have a high aspect ratio, run along the middle portion of each half-wing. The purpose of this arrangement is to utilise the action of the ailerons to the full and to eliminate the tip effect as far as possible. The fuselage, which is very large in comparison with the size of the aircraft, is square in section, rounded off forward and terminating in a spinner. The Salmson A.D.9 nine-cylinder 40 h.p. radial engine is carefully cowled in with only the cooling ribs of the cylinders projecting.

The two seats are arranged side by side, but slightly staggered in order to economise space.

The controls are of the usual lever and pedal type. The elevator is controlled by a system of rods, whereas the ailerons and rudder are controlled by cables. The tail plane is of the monoplane type and the fin and rudder can be taken down in a few seconds by the removal of a pin.

The tail plane, which is adjustable in flight, and the elevator can also be removed very quickly in a single unit. The wings are very easy to dismantle and can be fixed by means of their own attachments to the fuselage in order to facilitate transport. The undercarriage, which has two small wheels with very wide track, is exceptionally light and has a very low drag. The rubber cord shock absorbers are fitted inside the wing.

The specification is as follows :—

Wing span, 9.9 m. (32ft. 6in.).
Overall length, 5.5 m. (18ft.).
Overall height, 1.6 m. (5ft. 3in.).
Wing area, 10.5 sq. m. (113.1 sq. ft.).
Tare weight, 235 kg. (518 lbs.).
Useful load, 200 kg. (441 lbs.).
Total loaded weight, 435 kg. (959 lbs.).
Wing loading, 40 kg./sq. m. (8.1 lbs./sq. ft.).
Power loading, 4 kg./sq. m. (8.8 lbs./h.p.).

The S.63 New Commercial Twin-Engined Flying Boat.

L'Aviazione, October 8th, 1926. (71026)

A new commercial seaplane, the S.63, is now in course of construction at the Savoia Works at Sesto Calende and should be ready for test next spring. The S.63 is derived from the well-known S.55 and will have two 500 h.p. A.S.S.O. engines mounted in tandem above the monoplane wing. The wing area will be 120 square metres (1,293 sq. ft.) and the span 28 metres (91ft. 10in.). The S.63 differs from the S.55 mainly by the fact that instead of two small hulls it has one large central hull which gives facilities for a roomy and comfortable passenger cabin.

U.S.A.

The Cole Sport Commercial.

Aviation, October 11th, 1926. (81026)

The Cole Aircraft Corporation of Cleveland, Ohio, manufacturers of commercial aircraft, has recently produced an interesting airplane of comparatively low horse-power, which, for a stock commercial job, has a notable high speed combined with a quick take-off and a slow landing speed. This machine has been named the Cole Sport Commercial.

Characteristics and Performance.—The chief dimensions and the manufacturer's performance figures of the Cole Sport Commercial fitted with the OX-5 engine are as follows :—

Span (both wings), 27ft.
Chord (both wings), 4ft.
Gap at centre, 4ft. 2in.
Stagger, 1ft. 8in.
Incidence (upper wing), 0 deg.
Incidence (lower wing), 1½ deg.
Dihedral (upper wing), ½ deg.
Dihedral (lower wing), 1½ deg.
Length overall, 21ft.
Height, 7ft. 7in.
Area of horizontal tail surfaces, 29 sq. ft.
Area of vertical tail surfaces, 10 sq. ft.
Area of ailerons, 24 sq. ft.
Weight empty, 1,050 lb.
Useful load, 600 lb.
Wing loading, 8⅓ lb.
Power loading, 17½ lb.
Fuel capacity, 32 gal.
Endurance, at cruising speed, 4 hr.
Maximum speed, 120 m.p.h.
Landing speed, 45 m.p.h.
Climb to 1,000ft., 1 min. 57 sec.

The Meyers Midget.

Aviation, October 4th, 1926. (91026)

One of the new light planes developed during the past year and which made its first appearance at Philadelphia during the National Air Races was the Meyers Midget, a very small single-seater biplane with a Bristol Cherub III. engine of 30 h.p. The plane was, in fact, finished only just in time for the races and actually performed its first flight at Philadelphia at Model Farms Field on Monday evening (September 6th) after the last scheduled events of the races that day had been concluded. The Midget was designed by Charles W. Meyers, and constructed in the shops of the Kreider-Reisner Aircraft Co., Inc., of Hagerstown, Md.

Specifications.—The general specifications and details of the Meyers Midget are as follows :—

Span (upper wing), 16ft.
Span (lower wing), 12ft.
Length (overall), 13ft. 2in.
Wing area, total including ailerons, 70 sq. ft.
Wing area (upper wing), 45½ sq. ft.
Wing area (lower wing), 24½ sq. ft.

Angle of incidence (both wings), 3 deg.
Gasoline capacity, 2½ gal.
Oil capacity, 3 qts.
Weight empty, 304 lb.
Weight loaded (150 lb. pilot), 480 lb.
Weight of fuselage, landing gear, propeller, engine, tanks, cowling, stabiliser, elevators, rudder, 224 lb.
Weight, upper wing, ailerons and control cables, 37 lb.
Weight (lower wing), 12 lb.
Weight, interplane struts and truss bracing struts, 12 lb.

The Fairchild F.C.I.

Aviation, October 25th, 1926. (101026)

The plane is designed for the Fairchild-Caminez engine, but when equipped with the OX-5 only two passengers are carried.

General Details.—The main characteristics of the OX-5 plane and the certified performance figures are as follows:—

Span, 44ft.
Span (wings folded), 11ft. 9in.
Total wing area (including ailerons), 275 sq. ft.
Length, 30ft.
Height (ready for flight), 9ft. 4in.
Height (wings folded), 10ft.
Weight (light, with water), 1,596 lb.
Load, as follows:
Pilot, 165 lb.
Pay load (two passengers or freight), 330 lb.
Fuel and oil,* 240 lb.
Total useful load, 735 lb.
Total gross loads in tests, 2,331 lb.
Wing loading, 8.5 lb./sq. ft.
Power loading, 26 lb./h.p.
Capacity of fuel tank* (gravity feed), 35 gal.
Cubic capacity for cargo, 60 cu. ft.

* Since tests were made, a seven-gallon reserve tank has been added, giving five-hour cruising range, or 425 miles.

Performance.—Performance with OX-5 engine and 735 lb. load:—

Maximum speed (flaps up 2 deg.), 97.1 m.p.h.
Maximum speed (using flaps), 40.0 m.p.h.
Landing speed (not using flaps), 42.5 m.p.h.
Landing run (using flaps), 131.2 yd.
Landing run (not using flaps), 143.0 yd.
Take-off speed (using flaps), 37.0 m.p.h.
Take-off speed (not using flaps), 38.0 m.p.h.
Take-off distance (using flaps), 138.4 yd.
Take-off distance (not using flaps), 159.5 yd.
Climb in first 10 minutes, 3,200ft.
Initial rate of climb (not using flaps), 350ft./min.
Climb to 4,000ft. (flap setting increased to 4° down), 13.19 min.
Service ceiling (flaps increased to 8° down), 7,800ft.
Time to service ceiling, 38.7 min.
Absolute ceiling (flaps down to 8°), 8,640ft.
Absolute ceiling (flaps down 12°), 9,890ft.

Power Units and Fuels

Santos-Dumont's Heavy Oil Engine.

L'Aero Sports, October 9th, 1926 (France). (111026)

Santos Dumont has designed and constructed an engine which should do much to promote air traffic.

This engine will run on heavy oil which will render it very economical and eliminate all danger of fire.

It will be placed on the market under the name of "Moteur Santos Dumont-Soriano."

The Rickenbacker Engine Test-Flown.

Aero Digest, October, 1926 (U.S.A.). (121026)

The light-weight, medium horse-power, radial air-cooled motor has made its appearance, and with its production a noteworthy step forward has been made in commercial aeronautics.

The new motor is the Rickenbacker five-cylinder, 60 h.p., radial, air-cooled. It develops 60 h.p. at 1,650 revolutions per minute and approximately 75 h.p. at 2,400. It weighs less than 180 pounds ready to fly.

The first ship to be powered with it was the newest of the Driggs planes, the Driggs Coupe, built by the Driggs Aircraft Co., Dayton, Ohio. This ship was recently flown from Dayton to Detroit, 220 miles, by Jack Laass in two hours and a half. He averaged fifteen miles to a gallon of gasoline and used only one pint of oil. Laass test-flew the ship once, found the motor was working nicely, so he started for Detroit. "It shows plenty of confidence to do that with a motor just off the block," he said. "Another thing that I like about it is that I don't know of any other motor of only 60 h.p. that ever pulled a load of 1,500 lbs. off the ground and carried it at the rate of 85 miles an hour through the air."

In size the engine is ideal because it is adaptable to a wide range of application and several methods of installation. The motor is under 30 inches in overall diameter. The cylinder bore is four inches and the stroke three and one-half. This gives a total piston displacement of 220 cubic inches. It has fewer parts than the average automobile engine and may be repaired by a mechanic of ordinary ability.

There are several unique features of the motor. The aluminium gear case, for instance, attached to the rear of the crankcase, supports the cam ring and the oil pump as well as gears for driving same. The gear case may be removed and replaced without affecting the valve timing in the least, therefore, when the engine has once been timed there need be no fear of getting it out of adjustment during the inspection or while making repairs. The striking feature of this design is the single ring of three cams which operates all ten valves.

Each cylinder has two spark plugs. There are two five-cylinder, high-tension magnetos. The magnetos work independently, one firing the forward spark plugs and the other the rear plugs—in all cylinders—hence there is small possibility of a forced landing due to ignition failure.

Research on Oil-Injection Engines for Aircraft.

Mechanical Engineering, November, 1926 (U.S.A.). (131026)

This paper discusses the problem of the high-speed, high-capacity oil-injection engine, and describes some of the apparatus used and some of the results obtained in the fundamental studies conducted on oil sprays injected into compressed gases by high-speed cinema photography.

A Roots-type Aircraft Engine Supercharger.

J. Soc. of Automotive Industries, September, 1926 (U.S.A.). (141026)

A Roots-type supercharger is described and the results of laboratory and air tests are given. With full supercharging to 20,800ft. with a modified D.H.4 aircraft, the absolute ceiling was increased by about 92 per cent. and the service ceiling by 100 per cent. as compared with an unsupercharged aircraft of the same type. Although no air-cooler was used between supercharger and engine, the maximum carburettor air temperature at 20,000ft. was only 140°F.

Torsional Vibrations in Reciprocating Engine Shafts.

Physical Ber. 1621, 1926 (Germany). (151026)

The theory of torsional oscillations of slow running shafts in reciprocating engines, especially of six-cylinder, four-stroke cycle Diesel engines.

The usual theory replaces pistons, rods, cranks, etc., by equivalent masses.

The author attempts to correct for these approximations by assuming that the individual shafts are rigid. The values of the critical speeds show moderate departures from the simple theory which may be insignificant in practice.

Temperature Measurements of Light Alloy Pistons.

La Technique Moderne (France). (161026)

It was not found possible to take measurements with the engine running, but by braking the engine suddenly it was possible to take readings ten seconds after stoppage. The results show the effects of various factors on the piston temperature, amongst those examined being the effects of compression ratio, piston play, spark setting and mixture strength.

"Motalin," a petrol substitute to prevent detonation.

Motorwagen, October 20th, 1926 (Germany). (171026)

This fuel consists of 40 per cent. benzol and 60 per cent. petrol, with the addition of 0.2 per cent iron carbonyl. Iron pentacarbonyl Fe $(CO)_5$ is obtained by passing CO over finely-divided iron, the amount increasing with temperature and pressure from atmospheric up to 200°C. and 150 atmospheres. It is a reddish-yellow oil of sp. gr. 1.46.

M.P., 20°C. B.P., 103°C. Igniting temperature, 34°C.

Decomposed by sunlight into red crystals of Fe_2 $(CO)_9$.

The exhaust is not poisonous, whereas tetraethyl lead is poisonous.

The substance itself cannot be regarded as entirely non-poisonous, but with suitable precautions there is no danger.

Measurement of Fuel Drops in Mixtures for Internal Combustion Engines.

Zeits. Vereins deutsch. Ing. (Germany). (181026)

Research has been undertaken at Munich with a view to elucidating the mechanism of the production of an air fuel mixture. Apparatus has been devised for estimating the size of the fuel particles by a method of difference of electric potential and the density of their distribution in the mixture photometrically. It is intended to extend the work to an investigation on the influence of the variations of the type of fuel used and the engine cycle employed.

MATERIALS

Magnesium Alloys.

Automotive Industries, August 5th, 1926 (U.S.A.). (191026)

Experiments on various magnesium alloys have been reported upon by Portevin and Le Chatelier to the French Academy of Sciences. Among the

binary alloys of magnesium studied, those containing nickel and copper seem to hold out the greatest possibility of practical utility, while of the ternary alloys those containing nickel-copper and aluminium-copper seem to be of the most interest.

Aluminium Solders.

Engineer Supplement, October 29th, 1926 (Great Britain). (201026)

The note refers to an article in *Zeitschr. fr. Metallkunde* (July, 1926) in which it is stated that although the ordinary low melting solders are not satisfactory, the relatively high melting solders, consisting mainly of aluminium and applied with the aid of fluxes, have long been in entirely successful commercial use.

MISCELLANEOUS

The Stationary and Rotating Equisignal Beacon.

J. Soc. of Automotive Engineers, September, 1926 (U.S.A.). (211026)

Reference is made to the various means of direction finding and their respective advantages and disadvantages. The theory of the goniometer and types of loops are discussed, the equisignal method of signalling is explained, and the results of some experimental flights are given. The article is well illustrated.

Substitution of Mineral Oil for Castor Oil.

La Revue Petrolifiere (France). (221026)

A number of mineral oils for lubricating purposes have been experimented upon. The technical director of the Air Union has stated that mineral oils of good quality are suitable for the lubrication of most, but not all, the engines used in air transport, provided an oil tank with separator, an oil cooler and an oil purifier are used. Veedol Extra Heavy Oil has been in use on aircraft of the Latecoere Co. for some time and appears to have given complete satisfaction. Mobiloil B and Texaco oils are used as lubricants on a number of U.S.A. aircraft engines.

Sources of Contamination of Crankcase Oil.

J. Soc. of Automotive Industries, September, 1926 (U.S.A.). (231026)

The causes and effects of dilution are discussed and methods of separating out the contaminating material by filtration and evaporation are described. Prevention of dilution is said to have doubled the life of the engine and improved engine performance. The recommendation is made that all internal combustion engines be provided with suitable equipment for the positive prevention of dilution.

REVIEWS

Aerofoil and Airscrew Theory

By H. Glauert, M.A., Fellow of Trinity College, Cambridge. Pp. 228. Cambridge University Press, 1926.

Mr. Glauert was one of the first in this county to appreciate the fundamental work done by Prandtl and others in Germany, in putting Lanchester's theory, of circulation round a lifting wing and of vortices trailing from it, on a systematic basis suitable for furthering experimental research and for application in aeroplane design. Mr. H. M. Martin's brochure of 30 pages, *The Elements of the Lanchester-Prandtl Theory*, is the only previous English book on the subject, and students should read it as an introduction to the volume under review, and, as well, for Mr. Martin's mastery of elementary exposition. Mr. Glauert is thus also one of the first to produce a book in English. The first part of *Aerodynamik*, Fuchs and Hopf, Berlin, 1922, is the most comprehensive text book on the subject, and Fuchs's work offers a standard by which the book under review may be judged a satisfactory achievement.

Chapter I. defines lift, drag and moment coefficients and gives typical experimental values in graphical form as functions of incidence. Chapters II.-VII. give briefly some of the elements of rational hydrodynamics, particularly the methods of conformal transformation from flow round a circular cylinder to flow round wing profiles, of a perfect fluid, due to Kutta, Joukowsky and v. Mises. Chapter VIII. gives a slight sketch of the problem of form resistance, quoting the Kirchoff-Rayleigh result for surfaces of discontinuity, and v. Kármán's result for a stable series of alternate eddies. "Dimensional Theory" gets a page, the equations of viscous fluid motion get a footnote reference to Lamb, and various theoretical and empirical results for laminar flow (Blasius) and turbulent flow (v. Kármán) get citations.

Chapters XI.-XIV. contain the material which will be of most use to designers. Once we accept the existence of Lanchester's circulation and trailing vortices, and have determined the strength of the vorticity throughout the field by experiment, or by mathematical inference therefrom, the hydrodynamical analogue of the Biot-Savart law for the strength of the magnetic field due to electric currents enables us to determine the velocity field due to the known distribution of vortex filaments. The experimental determinations of lift and drag may now be analysed in the light of Lanchester's conception, and in German hands the method has yielded the scientifically interesting and practically important results, collected in these chapters.

The "induced" velocity field, the consequent changes in effective incidence and resistance, wind-channel interference, for various distributions of lift and types of channel, etc., are given in a form which every designer will readily adapt to his own note-book. The result in the section on rectangular channel interference was first given by Mr. Glauert, so far as the reviewer is aware.

Chapters XV. and XVI. on airscrews extend to 12 pages. The formulæ given will be useful to designers who have the usual elaborate arithmetical methods of design at their finger ends and can fill in coefficients from their accumulated experience. The alleged "independence" of blade elements has always been incomprehensible to the writer; "inter-dependence" seems a more suitable description of the facts. Chapter XVII. discusses very briefly channel interference with airscrews. Prandtl has shown that McKinnon Wood's correction is a rational one, and a reference is desirable. The difficult question of body interference is touched on and a method of experiment suggested.

Taking minor points of criticism somewhat at random, one notes sadly the introduction of a " metric slug " called a " Newton," and this in the University of Newton and Attwood! The reviewer prefers *thrust distribution, configuration of flow, dead water,* to the newer terms *thrust grading, flow pattern* and *stagnation point.* The treatment of the integral on pp. 92-93 and 139 (whether by Glauert, Martin or Prandtl) will scarcely satisfy mathematicians. An appeal to physics is really required to justify the use of the principle value.

On the vexed subject of references the reviewer takes the example set by, say, Prandtl and Lamb as reasonable. By their standard Mr. Glauert's detailed references are inadequate. Indeed a reader unfamiliar with the German literature of the subject could scarcely fail to get the impression that much original work is due to the author, which in fact is merely selected from the abundant German sources. In particular a reference should be given to Fuchs, whose Part I. of *Aerodynamik* has quite evidently influenced the author, both as to selection and arrangement of material.

Reference is frequently made to the author's own reports (R. and M. series) which are merely expository, where a reference to the original German work would appear to be sufficient. An exception should be made in the case of the extension of the method of images to the interference of square and rectangular channels. The principle is of course old, but the final convenient forumla given by Mr. Glauert is new so far as the present writer is aware. Here again, a reference should be given to v. Kármán or Lamb or Fuchs for the method of summation employed, instead of the unnecessary reference to Hobson's Trigonometry for an elementary relation which is merely the starting point of Lamb's worked out summation.

The general references are adequate and will introduce the reader to the most important German work. The author is to be complimented on this valuable feature of his book. The printing and diagrams are on the high standard expected from the Cambridge University Press, and no misprints have been noticed in a fairly close reading and verification of numerous formulæ. The book is an important contribution to English aerodynamical literature and should be of the greatest value to all designers of aircraft and of the greatest interest to all students of hydrodynamics.

A. R. L.

Australia and Back

By Sir Alan Cobham, K.B.E. (A. and C. Black, Ltd., 2/6 net.)

After Sir Alan Cobham had at last managed to get away from the cheering crowds which greeted him at Westminster on his triumphant return from his flight to Australia and back, after he had managed to break away from every official and non-official person who wanted to congratulate him, he wrote, " At the close of that tremendous day I think I went to bed convinced that at last the public realise the importance of aviation to every Briton, and—what is more —I felt that its imagination was aroused in support of its good cause."

Sir Alan Cobham has done more than any living Briton to prove to all the world that flying is as safe, as easy, and as exhilarating as any other form of motion. And now he has written a book upon a great flight, a book crowded full of interest and experiences from cover to cover, a book which should be read by everyone who is proud to claim Cobham as a countryman.

It is safe to say that several million people saw the little seaplane on its journey from Rochester and back. And it is safe to say that many thousands who watched it have become converted to the ways of the air. The enthusiasm all the way was tremendous. At Melbourne, for example, a crowd of 150,000 waited for that ever-growing speck in the sky, and when that speck landed a hundred and fifty thousand people rushed forward all eager to shake Cobham

by the hand. It took all the efforts of the police to protect him, and so great was the desire to be round and near the great little man that the official reception had to be abandoned. The officials could not get near Cobham to greet him.

Adventure, thrills, ease and toil, hopes and fears, conquest and temporary defeat, all are in this book, all prove that the spirit of Drake and Raleigh, of Franklin and Livingstone, still lives in the modern world.

An excellent gift book for the ambitious boy.

BRANCH NOTICES

COVENTRY BRANCH

Hon. Sec., F. MEADOWS, Esq.

General Meeting

The Annual General Meeting was held on the 7th January, 1927, Major F. M. Green (Fellow) presiding.

Mr. J. D. Siddeley was re-elected President; Major F. M. Green, Vice-President; and Mr. F. Meadows, Hon. Secretary.

The same Committee as last year were re-elected with the addition of Messrs. H. O. Towns and W. C. Maton.

The balance sheet was approved and adopted.

Referring to the balance sheet, this result was only made possible by Mr. Siddeley kindly giving the free use of the lecture hall, cinema machine, etc., and by Major Green taking care of the comforts of our lecturers.

The first lecture this year will be by Sir Quentin Brand on "The Pioneer Flight to the Cape," and is provisionally arranged for the 24th February.

COVENTRY BRANCH OF THE ROYAL AERONAUTICAL SOCIETY.

Balance Sheet for the Year ending December 31st, 1926.

Receipts.

	£	s.	d.
Subscriptions of 229 Members ...	57	5	0
Journals ordered and paid for by Members	1	3	10
	£58	8	10

Expenditure.

	£	s.	d.
Journals (as ordered)	1	3	10
Lecture Expenses	7	10	3
Empire Tickets	9	1	0
Works Visit	2	12	0
Stamps	1	1	0
'Phone and Telegrams		2	2½
Cheque Book		2	0
Clerical Expenses		2	0
	21	14	3½
Cash in hands of Hon. Sec. ... £0 18 3½			
Stamps in hands of Hon. Sec. ... 0 2 9			
Cash at Bank, Dec. 31, 1926 ... ... 35 13 6			
	36	14	6½
	£58	8	10

7th January, 1927.

Audited and found correct.
(Signed) H. WOODHAMS.
ARTHUR SMITH.

YEOVIL BRANCH

Hon. Secretary, V. S. GAUNT, Esq.

Lecture Dates

The following alterations are made in the syllabus of the Ground Engineer's lectures published in the January Journal:—

Mr. Robson will give his lecture on "Compasses—Installation and Swinging," on February 13th, instead of March 9th. On February 23rd, Mr. S. G. Williams, A.M.I.M.E., Air Ministry, will lecture on "Metals and Their Heat Treatment," in place of Mr. Goswell's lecture on "Workshop Processes," which will be given on March 2nd. On March 9th, Captain L. Warner, A.M.I.A.E., Air Ministry, will lecture on "Power Plant Installation." And on March 23rd, Mr. R. C. Taylor will lecture on "Inspection and Checking of Components," in place of Captain Keep's lecture on "Equipment Installation."